HIGHWAY RESEARCH RECORD

Number 350 | Symposium on Viscosity Grading of Asphalts

6 Reports

HIGHWAY RESEARCH BOARD

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Number 350 | Symposium on Viscosity Grading of Asphalts

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Subject Area

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W. G. Gunderman, Highway Research Board staff

FOREWORD

It is of interest to note that 4 of the 5 papers included in this RECORD reflect the addition of viscosity controls to the familiar consistency controls for asphalt cements. The papers from 1 state and 2 provinces show such changes, and AASHO has adopted a viscosity-grading specification. One paper presents a study of the changes in bituminous concrete pavement properties with service.

The use of asphalt cement in bituminous concrete mixtures requires the engineer responsible for the quality of the material to have knowledge of the consistency of the asphalt during mixing, transporting, placing, and early traffic loading especially in hot weather in order to avoid or minimize mixture failures, such as incomplete coating and harmful flow of coating during transporting and paving. In addition, knowledge of the consistency under high summer temperatures and shear properties under low winter temperatures is needed to be in position to provide suitably durable pavements.

Under this range of temperatures, it is apparent that the asphalt cement in bituminous concrete occurs as a liquid during mixing, transporting, and possibly placing, as a plastic possibly during placing and under subsequent use by traffic, and as a solid when cold. Knowledge of the consistencies under all conditions is needed for success in achieving a satisfactory pavement. It is demonstrated in these papers and elsewhere that some asphalt cements with consistencies suitable for mixing will have a consistency after spreading such that rolling must be delayed appreciably, whereas bituminous concrete with other asphalt cement can be compacted promptly. Asphalt cements having suitable consistencies at mixing and placing may not have the optimum properties for low temperature service without cracking. Also, asphalts with suitable properties to withstand cracking during long periods of severe cold may not have the most desirable consistencies for either mixing or laying or both.

These elements were less evident in the early days of bituminous concrete construction when asphalt cement was available from only a few sources, and controls by means of penetration, ductility, and softening-point tests for the consistency characteristics were adequate. At present, however, crude oils from a wide geographical range are available to a single asphalt producer with the possible result of producing asphalts of different consistency characteristics during different periods of the year. In addition, new crude oil sources may result in the production of asphalt cements with consistency characteristics different from the characteristics of those now available.

The paper by Fromm and Phang points to the need for additional viscosity control in addition to penetration in order to correct for undue delay of the compaction operation. The asphalt cement specification currently used by the Department of Highways, Ontario, is of interest.

The paper by Skog and Sherman also illustrates the use of an added viscosity control to result in better pavements at construction along with the rolling thin-film oven test to measure the changes that occur during mixing. Although specification requirements are not included, there are substantial data concerning the viscosity-penetration relationship under different conditions.

The paper by Anderson and Shields compares cracking results for asphalts of 200 to 300 penetration range and different viscosities and provides information concerning the present Alberta practice for specifying asphalt cements. The viscosity data reflect changes that occur in service as well as differences in the original materials. Tensile splitting data are also included.

Halstead and Welborn provide an excellent background for the extensive work leading to the adoption of AASHO M 226-70I, Asphalt Cement Viscosity Graded at 140 F. Some of the arguments opposing such a specification are also discussed.

Changes in the original properties of asphalt cements that occur with aging in thin films must also be identified and controlled where such aging adversely affects the durability of the pavement. It has been established that in many cases adverse aging of asphalt cement can be minimized by the use of suitable mix designs.

The paper by Gotolski, Smith, and Roberts presents extensive data concerning the field condition of the test pavements as well as the association of the asphalt cement properties in service with the air void contents after periods of service.

Davis has supplied a general discussion on the problem of measuring asphalt-cement properties, especially at low temperatures.

—F. M. Williams

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DEVELOPMENT OF SPECIFICATIONS FOR VISCOSITY-GRADED ASPHALTS

Woodrow J. Halstead, Materials Division, Federal Highway Administration; and
J. York Welborn, Consulting Engineer

The users and producers of asphalt have conducted a comprehensive research program to develop fundamental methods for measuring the consistency of asphaltic materials and to study the flow properties of asphalt cements over the range in temperatures encountered in construction and service in pavements. Concurrently a number of specifications using requirements based on the new fundamental methods have been proposed or used as the basis for purchasing asphalt. In an attempt to give some guidance and standardization to these specifications, the Committee on Materials of the American Association of State Highway Officials (AASHO) undertook the development of specifications based on viscosity grading at 140 F. Four grades were selected, and limiting requirements were added for viscosity at 275 F. Because low-temperature viscosity tests were not perfected for national use, limiting requirements using the penetration test at 77 F were selected. Other requirements included maximum viscosity and minimum ductility limits on the residue from the thin-film oven test. Conventional solubility, flash point, and Oliensis spot test requirements also were included in the specification. The limits for the requirements of the 4 grades were set by a systematic study of test characteristics of asphalt cements produced in the United States. The specification has been adopted by AASHO, designated as Specification M 226, and published as an alternate to Specification M 20, which is based on penetration grading and remains in effect. The advantages of Specification M 226 are that it provides information on the kind of asphalt being used and a means for selecting the asphalt that should result in improved mixture design and more uniform construction practices. This should, in time, lead to improved pavement performance.

•ABOUT 10 years ago the users and producers of asphalt became keenly interested in the development of fundamental methods of measuring the flow properties of asphaltic materials. This interest was prompted by the limitations of the usual empirical tests then in use and the desire to better define the rheological or engineering properties of asphalt and to use such information for establishing more rational requirements for specifications. This interest resulted in a considerable number of studies by both producers and consumer groups, such as the Federal Highway Administration, The Asphalt Institute, state highway departments, and individual private companies producing asphalt products. During this period, test methods for measuring fundamental viscosity at temperatures ranging from 32 to 300 F have been developed and standardized by both the American Society for Testing and Materials (ASTM) and the American Association of State Highway Officials (AASHO). The fundamental flow properties of asphalts have been studied in both laboratory tests and field experimental projects. Concurrently, a number of specifications have been proposed and in some instances used as the basis for purchasing asphalts for construction.

Sponsored by Committee on Characteristics of Bituminous Materials and presented at the 50th Annual Meeting.

Little or no controversy developed with respect to fundamental viscosity, or more specifically kinematic viscosity, requirements for liquid asphalts. The application of the concepts to paving-grade asphalt cements, however, has proved to be extremely controversial, and valid differences of opinion, each of which is scientifically and technologically sound, have arisen.

For liquid asphalts, essentially a constant conversion factor was determined for converting the empirical Saybolt-Furol viscosity requirements to kinematic viscosity equivalents. The ability to determine kinematic viscosity at 140 F for all grades of liquid asphalts quickly and accurately led to early acceptance of the new system and units in specifications for these materials. As the authors (1) of this paper predicted in 1962, the problem with respect to asphalt cements has been more difficult. At that time we stated the following:

> However, the adoption of fundamental units to asphalt cements, with the complete elimination of the penetration test, presents very complex problems. These problems are: (a) Asphalt cements differ widely in viscosity-temperature susceptibility so that materials of equal viscosity at one temperature may have widely different viscosities at other temperatures. (b) Asphalt cements at atmospheric temperatures exhibit complex flow properties. The degree of complex flow differs for asphalts produced from different crude sources and by different methods of refining. (c) The degree of complex flow changes with temperature changes for individual asphalts; it also changes during hardening in service.

In reviewing the activities of the past 8 years, we find that these predictions of complications have proved to be only too true. Nevertheless, the knowledge gained by studying the flow properties of asphalts produced and used in the United States and Canada over a wide range in temperature has given the researcher and engineer a far better understanding of the complex rheology of asphalt and its effect on mixture design, pavement construction, and performance during service under varying environmental conditions. Thus, despite the differences of opinion that still exist, a number of the objectives of the initial program have been attained.

In our opinion, the original objectives have sometime been overlooked in some of the discussions surrounding the various proposals for specifications of asphalt cements based on viscosity grading. The purpose of this discussion is to attempt to place the various viewpoints in proper focus by relating how the AASHO Committee on Materials undertook the development of specifications for asphalt cements based on grading by viscosity at 140 F. Some of the considerations on which its decisions were based are also included.

REQUIREMENTS BASED ON FUNDAMENTAL FLOW PROPERTIES PROPOSED

For implementing the results of many of the studies, a number of different approaches have been suggested with respect to the adoption of fundamental viscosity requirements in specifications for asphalt cements. The following are some of these:

1. Grade by penetration at 77 F and use viscosity requirements at 140 or 275 F or both to control limiting flow properties;
2. Grade by viscosity at 140 F on asphalt as supplied with limiting requirements on viscosity at 275 F;
3. Grade by viscosity at 140 F on the residue from a thin-film oven test (TFOT) with limiting requirements on viscosity at 275 F; and
4. Grade by viscosity at 140 F with limiting requirements on viscosity at 275 F and additional requirements on consistency at low temperatures such as viscosity at 60 or 77 F or penetration at 60 or 77 F.

The AASHO committee made the decision to use the fourth alternative listed. Because a number of minor differences existed in the viscosity limits of the different grades in proposed specifications, the committee then made a judgment decision that the needs of the highway departments could best be met by 4 grades, AC-5, AC-10,

AC-20, and AC-40. The designated number of the grade is the target value in poises at 140 F divided by 100. The tolerance established for each grade limit was then set at ±20 percent of the basic value. Thus, the limits at 140 F for the various grades are as follows:

Grade	Limits (poises)
AC-5	500 ± 100
AC-10	1,000 ± 200
AC-20	2,000 ± 400
AC-40	4,000 ± 800

A task force was charged with developing other requirements for the specification. Because of the wide diversification of flow properties of asphalts produced from petroleum crude sources and refining methods used in the United States, the development of a specification that could be directed toward national use was not easy and some compromises were required.

TEST DATA ANALYZED

In accomplishing its work, the task force made extensive use of test data for a representative group of asphalts produced in the United States. These asphalt cements, graded by viscosity to meet the study specification of The Asphalt Institute, were obtained from 15 sources in 1965. They were selected to provide the maximum range in low-temperature flow properties that could be predicted from test data on penetration grades. The asphalt samples were thoroughly analyzed by The Asphalt Institute, by some state highway departments, and by the Federal Highway Administration. Most of the data used by the task force are those developed by the Materials Research Division of the Federal Highway Administration and reported in 1966 (2).

Because the AASHO specification was for national use, limits were sought that would to the extent possible take into account the wide range in flow properties before and after laboratory aging for all asphalts supplied in the United States. At the same time such limits should be sufficiently selective to rule out unusual or extreme materials.

Initially a specification was drafted with a number of alternate requirements based on available test data on typical viscosity-graded asphalts. The tests and test requirements suggested were considered suitable for use in a transition type of specification, incorporating viscosity with conventional penetration, ductility, and thin-film oven tests. The alternate requirements are given in Table 1.

TABLE 1

ALTERNATE SPECIFICATION REQUIREMENTS FOR VISCOSITY-GRADED ASPHALT CEMENTS

Test	Test Method	Viscosity Grade			
		AC-5	AC-10	AC-20	AC-40
Viscosity at 140 F, poise	T202	500 + 100	1,000 + 200	2,000 + 400	4,000 + 800
Viscosity at 275 F, centistoke	T201	110+	150+	210+	300+
Viscosity at 60 F, Mp		-16	-30	-68	-140
Penetration at 77 F	T49	120+	70+	40+	20+
Penetration at 60 F	T49	40+	24+	14+	8+
Ductility at 77 F, cm	T51	100+[a]	100+	100+	50+
Solubility in trichloroethylene, percent	T44	99.0+	99.0+	99.0+	99.0+
Flash point, COC, F	T48	350+	425+	450+	450+
Flash point, PMCC, F	T73	350+	375+	400+	400+
Thin-film oven test	T179				
Viscosity of residue at 140 F, poise	T202	1,500 ± 500	3,000 ± 1,000	6,000 ± 2,000	12,000 ± 4,000
Viscosity of residue at 140 F, poise	T202	-2,000	-4,000	-8,000	-16,000
Penetration of residue at 77 F	T49	60+	38+	24+	15+
Penetration of residue at 60 F	T49	20+	10+	6+	3+
Ductility of residue at 77 F, cm	T51	100+	50+	20+	10+
Ductility of residue at 60 F, cm	T51	40+	15+	6+	3+

[a] If the penetration is more than 200 and the ductility at 77 F is less than 100 cm, the material will be acceptable if its ductility at 60 F is more than 100 cm.

SPECIFICATION REQUIREMENTS SELECTED

The methods used for selecting the tests and test requirements and the possibility of using alternate requirements are included in the following discussion.

Figure 1 shows the relation of viscosity at 140 F to the viscosity at 275 F for asphalt cements from different sources. Essentially linear relationships result when the viscosities of the different grades from each producer source are plotted on log scales.

Asphalts J and O represent the extreme range for each viscosity grade and K represents one of the intermediate sources. Of particular interest is the narrow range in viscosity at 275 F for each grade demonstrating the uniformity in consistency in the temperature range of 140 to 275 F.

The horizontal line for each grade represents the minimum requirement for viscosity at 275 F. The limits are approximately the same as those proposed in the Research Specification of The Asphalt Institute. As shown in Figure 1, none of the asphalts in the series of study asphalts would fail these limits.

The need for some type of low-temperature consistency requirement has been stressed by the Federal Highway Administration and other groups from the time viscosity grading was first proposed. This was discussed earlier by the authors (1). Probably the most adverse criticism to using a viscosity-graded system at 140 F is the wide range in apparent penetration or apparent viscosity at low temperatures that would be permitted. The obvious objective is to measure the apparent viscosity directly, and much work has been done to develop low-temperature viscosity tests suitable for control of this property. However, they are complicated and are not developed to the state that they can readily be implemented for specification purposes. The most logical alternative for the present, therefore, appeared to be the use of the penetration test for the lower temperature control point. Two possible temperatures for penetration requirements were considered, penetration at 60 F and penetration at 77 F.

The range in penetration at 60 F for asphalt cements produced in the United States for each viscosity grade is shown in Figure 2. Asphalt sources E and J represent the approximate maximum range of asphalts supplied in the United States; I, K, and O are typical intermediate sources. The mean values for about 150 asphalts fall between the curves for asphalt sources I and J. Obviously the range in penetration for each viscosity grade is extremely wide when considered on a national basis. Also, the range

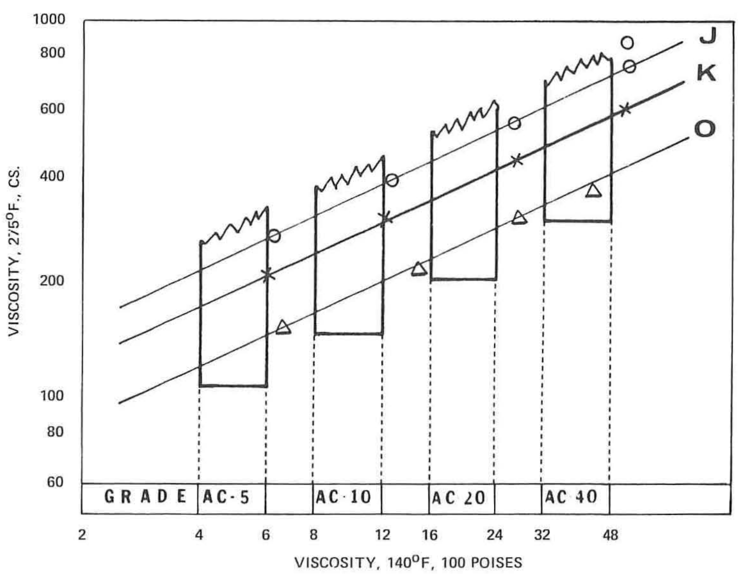

Figure 1. Relation between viscosity at 140 F and viscosity at 275 F.

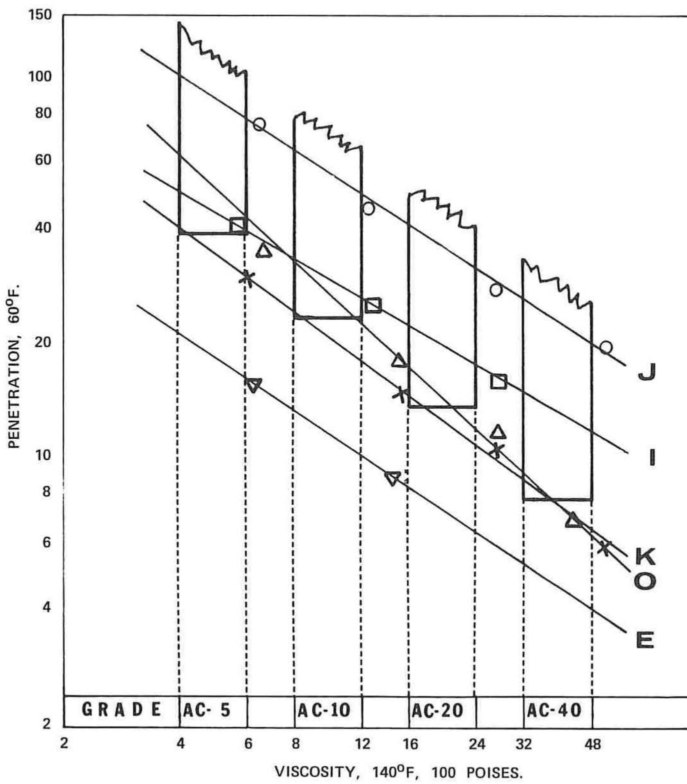

Figure 2. Relation between viscosity at 140 F and penetration at 60 F.

would vary depending on the specific marketing area. Because asphalts from source E are known to be extremely shear susceptible, are subject to brittleness at low temperatures, and would require special design considerations when used, it was considered reasonable to set limits in the guideline specification that would not be met by such materials. Consequently, as shown by the horizontal lines for each grade in Figure 2, the following limits for penetration at 60 F were considered:

Grade	Penetration at 60 F
AC-5	40+
AC-10	24+
AC-20	14+
AC-40	8+

Figure 3 shows a similar consideration for penetration values at 77 F. Essentially the same pattern emerges. Because penetration at 77 F has the advantages of providing a familiar "tie-in" with well-established values under the older system and is also in a range of more easily controlled temperatures with higher numerical results subject to less experimental error, penetration limits at 77 F were chosen as the basis for the specification control. The limits were set as follows:

Grade	Penetration at 77 F
AC-5	120+
AC-10	70+
AC-20	40+
AC-40	20+

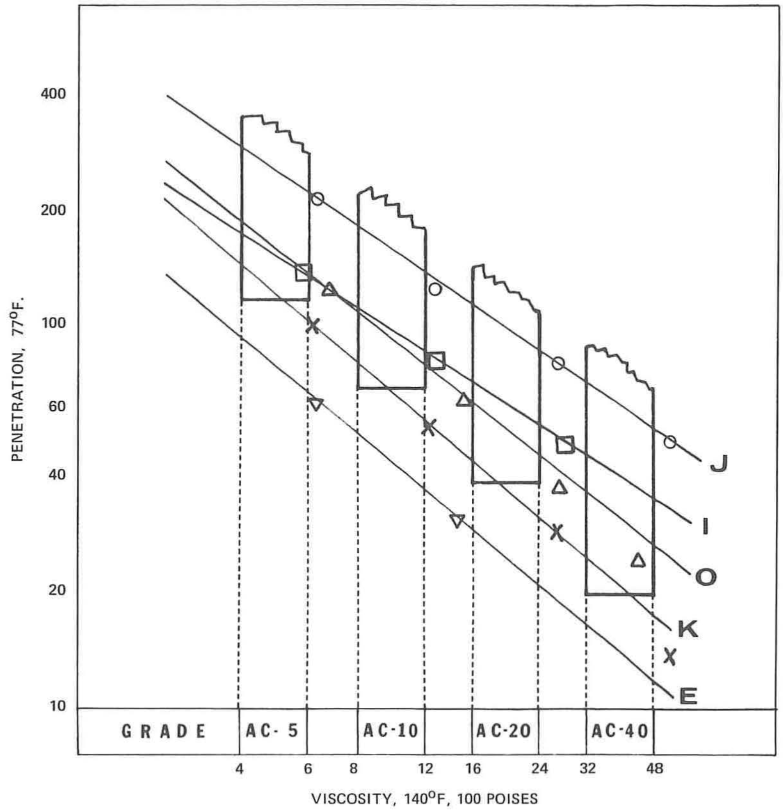

Figure 3. Relation between viscosity at 140 F and penetration at 77 F.

Even though this decision to use penetration at 77 F in the viscosity-graded specification is not consistent with the objective to eliminate empirical tests, it provides the desired degree of control of viscosity and has practical advantages in acceptance testing.

Consideration was given to The Asphalt Institute's proposal to use viscosity at 60 F as a specification requirement; but, because of the complex nature of the test and the lack of testing apparatus in many states and producer laboratories, it was not thought suitable for routine use at the present time. Figure 4 shows the range in viscosity at 60 F at a shear rate of 0.05 sec^{-1} for the asphalts studied. As previously shown for 60 F in Figure 2, asphalts E and J are the extremes, and asphalts I, K, and O are intermediate materials. The maximum requirement considered for each viscosity grade is shown by the horizontal line for each grade. The limits were set to give approximately the same level of control as the requirements for penetration at 60 and 77 F. The Asphalt Institute proposed an equation and a chart for approximately converting penetration at 60 F to viscosity at 60 F. However, the use of conversion of penetration to viscosity for specification purposes probably would create acceptance problems.

In summary, the consistency control selected for the AASHO specification included viscosities at 140 and 275 F and a penetration at 77 F.

The need for specification requirements to control hardening of asphalt during construction and service in pavements is well recognized. The TFOT has been established to be adequate to measure and control hardening characteristics of asphalts during hot plant mixing. Studies by the California Division of Highways and others have shown that the rolling TFOT can be used as an alternate to the standard TFOT.

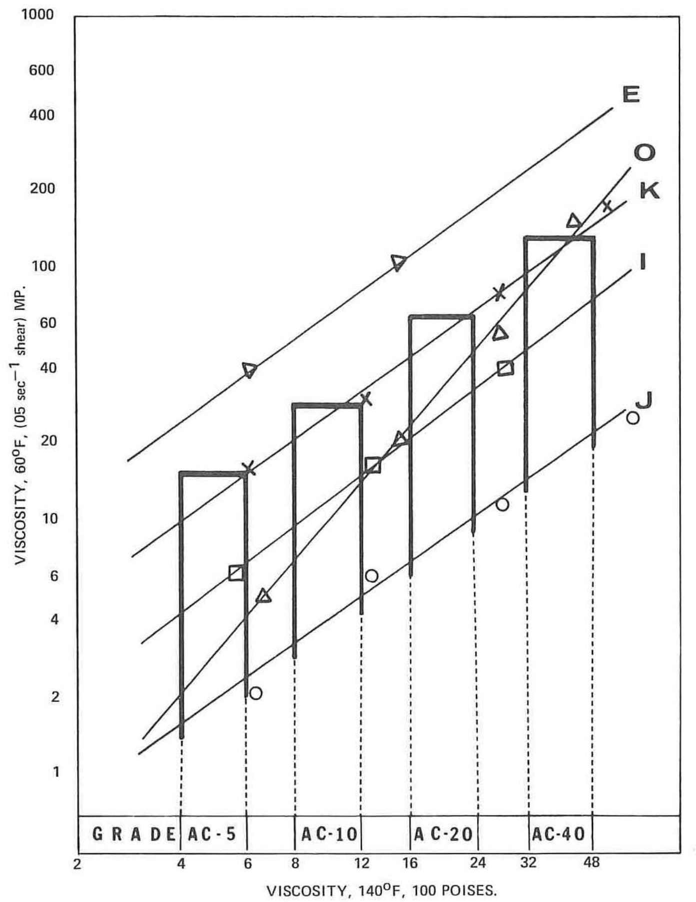

Figure 4. Relation between viscosity at 140 F and viscosity at 60 F.

The following alternative requirements to control hardening were considered for the AASHO specification:

1. Viscosity ratio at 140 F after and before TFOT,
2. Viscosity ratio at 60 or 77 F after and before TFOT,
3. Maximum viscosity at 140 F after TFOT, and
4. Range in viscosity at 140 F after TFOT.

To ensure more uniformity in consistency during construction, the hardening preferably should be controlled by a range in viscosity at 140 F on the thin-film residue. The principle is similar to the California proposal to grade asphalts after a thin-film test. Figure 5 shows the relation between viscosity at 140 F before and after the TFOT and the approximate maximum range for asphalts produced in the United States. Asphalts A and J had the highest viscosity after the TFOT, and asphalt O had the lowest viscosity. As shown by the blocks for each grade, the following maximum and minimum requirements for viscosity of residues after the TFOT were considered:

Grade	Maximum and Minimum
AC-5	1,500 ± 500
AC-10	3,000 ± 1,000

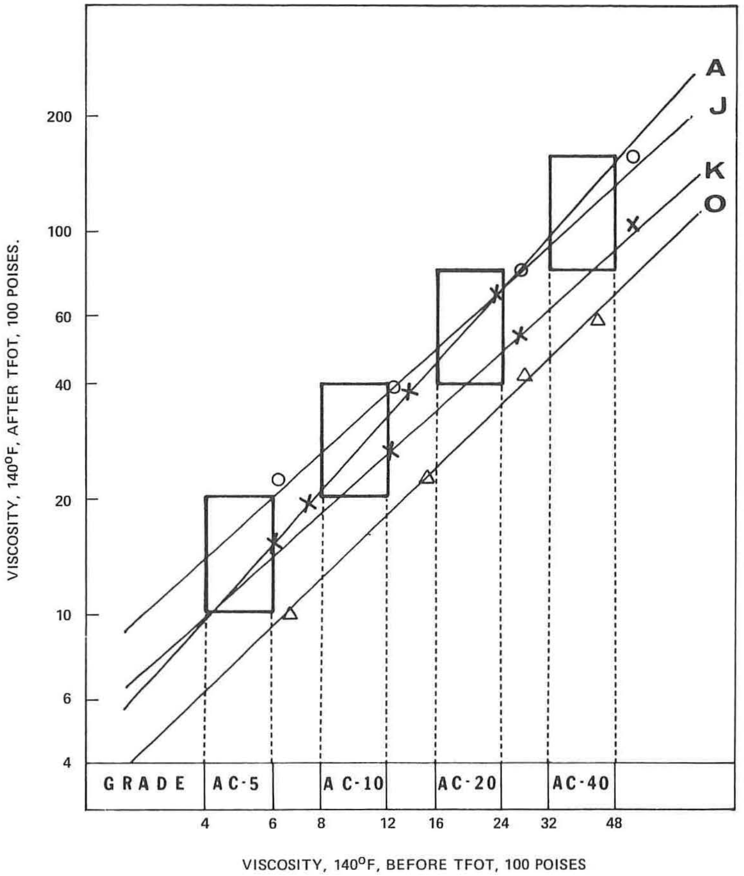

Figure 5. Relation between viscosity before and after thin-film oven test.

Grade	Maximum and Minimum
AC-20	6,000 ± 2,000
AC-40	12,000 ± 4,000

The use of these ranges in viscosity, together with viscosity requirements before the TFOT, was found to be somewhat restrictive when applied to a national specification. Therefore, the alternative of using only a maximum viscosity at 140 F on the residue was considered. The maximum limiting value shown in Figure 5 is 4 times the target grade viscosity before the TFOT. The requirements should provide for the proper protection against undue hardening and are not unduly restrictive for a national specification. The maximum limits shown in Figure 5 were, therefore, adopted for the AASHO specifications.

Considerable opposition has been expressed by some of the asphalt producers to the use of a ductility requirement on thin-film residue on the premise that, although some asphalts have ductilities below the national average and in some cases do not meet the present requirement in AASHO specification M 20 for penetration-graded asphalts, they still provide good service. However, there is enough evidence from previous studies (3, 4) to show that a minimum ductility is necessary to provide some assurance of better performance. Studies by the Federal Highway Administration (5, 6) also have shown that some asphalts have a high loss in ductility when heated to temperatures encountered

in construction. Therefore, the AASHO task force decided that a requirement for ductility on the thin-film residue serves a useful purpose and should be included in the viscosity-graded asphalt specifications.

By using ductility data on the TFOT residues of viscosity-graded asphalts and 88 other asphalt samples, the following limits at 77 F and 60 F were considered for the AASHO specification:

Grade	Ductility at 77 F	Ductility at 60 F
AC-5	100+	40+
AC-10	50+	15+
AC-20	20+	6+
AC-40	10+	3+

A ductility at 60 F offers some advantage because most asphalts have ductility values within the limit of the usual testing machine and may provide a better means for evaluating the asphalts. However, because experience and most of the field performance information is related to ductility at 77 F, the task force adopted the requirements at 77 F.

Requirements also were adopted for flash point (Cleveland open cup, COC), the spot test, and solubility in trichloroethylene. The limits set are comparable to those in AASHO M specifications for penetration-grade asphalts. Thus, an AASHO specification based on viscosity grading at 140 F containing the following requirements has been written and adopted: viscosity at 275 F; penetration at 77 F; flash point, COC; solubility in trichloroethylene; spot test with alternate solvents; and thin-film oven test, viscosity of residue at 140 F, and ductility of residue at 77 F.

The specification was published in July 1970 as an interim specification and assigned number M 226-70I. It will be published in the new tenth edition of AASHO standards to be released in 1971 as a full standard. The new specification can be used as an alternate to the penetration-graded specification M 20 that remains in effect. A copy of the complete specification is shown in Figure 6.

The AASHO specification as adopted will be quite lenient in some states but in others will eliminate some asphalt as now manufactured. We recognized that the supply situation or past practices may make it necessary and justifiable for individual states or groups of states to modify requirements based on their needs. The development of current information on the characteristics of asphalts being furnished the states should provide a basis for future revision of the AASHO specification. Consideration might be given to the California approach to place more control on the properties of the residue from a TFOT. With the approved capabilities of states to determine viscosities at low temperatures, requirements based on viscosity should be considered as a replacement for the present penetration limits at 77 F. For any adjustments in the proposed limits, we strongly recommend that use be made of the relationships shown in Figures 1 through 5. Arbitrary shifting of limits without regard to the interrelationships among test characteristics within grades and among the different grades of asphalt from the same source could lead to unjustified inequities.

PROS AND CONS OF VISCOSITY GRADING

After the specification was prepared by the AASHO task force, it was circulated to the major asphalt producers for comment. Comments varied all the way from the "limits are too restrictive" to "limits are not restrictive enough." Perhaps the greatest concern expressed related to multiple tanks needed by producers selling to some states using the old system and to other states using the new specification. This is a matter of legitimate economic concern, and it is hoped that neighboring states or groups of states will cooperate to the extent possible in changing over to new specifications.

Some of the comments received indicated a lack of understanding of the basis of the specifications. It was also indicated that the problem of chosing the proper grade of asphalt or the proper mix design was being confused with the asphalt specification re-

SPECIFICATION FOR VISCOSITY GRADED ASPHALT CEMENT

AASHO Designation: M 226-70 I

SCOPE

1.1 This specification covers four grades of asphalt cement graded by viscosity at 140F (60C) for use in pavement construction. For asphalt cements graded by penetration at 25C (77F) see AASHO Specification M 20, for Asphalt Cement.

MANUFACTURE

2.1 The asphalt cement shall be prepared from crude petroleum by suitable methods.

REQUIREMENTS

3.1 The asphalt cement shall be homoegeneous, free from water, and shall not foam when heated to 175C (347F).
3.2 The grades of asphalt cement shall conform to the requirements given in Table 1.

SAMPLING

4.1 Samples of asphalt cement shall be obtained in accordance with AASHO Method T 40, for Sampling Bituminous Materials.

METHODS OF TEST

5.1 The properties of the asphalt cements shall be determined in accordance with the following standard methods of the American Association of State Highway Officials:

Viscosity at 140F (60C)	T 202
Viscosity at 275F (135C)	T 201
Penetration	T 49
Flash Point	T 48
Solubility in Trichlorethylene	T 44
Thin-film Oven Test	T 179
Ductility	T 51
Spot Test	T 102

TABLE I

REQUIREMENTS FOR A SPECIFICATION FOR ASPHALT CEMENT – VISCOSITY GRADED AT 140F (60C)

AASHO Designation: M 226

Test	Viscosity Grade							
	AC-5		AC-10		AC-20		AC-40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity, 140F (60C), poises	500±100		1000±200		2000±400		4000±800	
Viscosity, 275F (135C), Cs	110	–	150	–	210	–	300	–
Penetration, 77F (25C), 100g, 5 sec.	120	–	70	–	40	–	20	–
Flash Point, COC, F	350	–	425	–	450	–	450	–
Solubility in trichlorethylene, percent	99.0	–	99.0	–	99.0	–	99.0	–
Tests on residue from Thinfilm oven test:								
Viscosity, 140F (60C), poises	–	2000	–	4000	–	8000	–	16000
Ductility, 77F (25C), 5 cm per min., cm	100	–	50	–	20	–	10	–
Spot test (When and as specified. See Note 1) with:								
Standard naphtha solvent	Negative for all grades							
Naphtha-Xylene-solvent, ____ percent xylene	Negative for all grades							
Heptane-Xylene solvent, ____ percent Xylene	Negative for all grades							

Note 1. – The use of the spot test is optional. When it is specified, the Engineer shall indicate whether the standard naphtha solvent, the naphtha-xylene solvent, or the heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of xylene solvents, the percentage of xylene to be used.

Figure 6. New AASHO specification.

quirements. For this reason, the following general summary of the problem appears to be in order.

One of the opposing views of viscosity grading at 140 F centered on the problems arising from differences in viscosity-temperature susceptibility of asphalts and the problems of pavement cracking often attributed to the asphalt being too hard. A possibility of brittle pavements due to excessive stiffness from too hard asphalts was shown. However, the illustrations given were based on no controls on consistency of the asphalts at lower temperatures. The minimum limit on penetration at 77 F in the proposed AASHO specification tends to eliminate the extreme conditions. Admittedly, large differences in low-temperature rheology would still exist, but the problem could be further guarded against by specifying a different grade asphalt and by modification of mix design to provide optimum conditions. If necessary, further low-temperature restrictions could be used. The need for these actions under viscosity grading should not be much greater than that which now exists for penetration grading.

The philosophy behind proper mix design using the viscosity-grading system is often overlooked. The basis for designing the mixture, in part, is to provide adequate stability (or stiffness) at the highest summer temperature and at the same time to avoid extreme brittleness that might lead to pavement cracking during the winter. By vis-

cosity grading at 140 F, the differences in binder consistencies for the same grade are reduced to a minimum if the design temperature is 140 F (7). If binder consistency is correct at this temperature, research as well as experience has shown that the temperature ranges for mixing and compaction for a given grade are for all practical purposes the same regardless of the source of the asphalt. At low temperatures, we are concerned with a critical consistency that, if exceeded, could result in extreme brittleness and consequent cracking or other deterioration in the pavement. Although this critical consistency is not necessarily viscosity per se, it most likely is directly related to viscosity or apparent viscosity. We must admit that at present we do not have clear-cut answers to this problem. However, the range between the maximum and minimum stiffness modulus for a given grade that was emphasized in some of the comments as being too great for some asphalts is not the primary concern and is not necessarily related to the performance of the mixture. We are concerned only that critical values at either the soft or hard end of the scale are not exceeded. A range of satisfactory values exists in which the asphalt viscosity has relatively little effect on performance for given conditions.

We know also that the critical mixture consistency (or stiffness) is not a function of the binder viscosity alone. This depends on a number of additional factors such as type and gradation of aggregate, type and amount of mineral filler, asphalt content of the mixture, temperature during service, traffic conditions, and type of base. Additional complications arise from the different degrees of shear susceptibility present in different asphalts at low service temperatures. Thus, the problems created by low and high temperature during service cannot be solved by viscosity grading of asphalts but with the application of proper mix design techniques; it is improbable that such problems will be aggravated. In addition, the use of the proposed AASHO specification containing consistency measurements at 3 points should serve as an automatic indicator of the characteristics of the asphalt being used, and considerations can be given to unusual materials during the mixture design. Any significant change in asphalt viscosity-temperature susceptibility during the progress of a job would automatically show up through acceptance testing. Under the present penetration specifications, such information is not automatically revealed by acceptance testing. It is important to point out that the AASHO use of a third consistency point is a departure from the research specifications of The Asphalt Institute that were the basis of some of the fear of extreme differences resulting from different asphalt viscosity-temperature susceptibilities.

As previously pointed out, the proposed AASHO specification (7) retains a link with past experience by requiring a measurement of the penetration at 77 F. However, the point needs to be made that a serious mistake can be made if one attempts to equate our knowledge of performance of penetration grades to a predicted performance of viscosity grades on the basis of substituting a single viscosity grade for a single penetration in all instances, for example, AC-10 for 85 to 100. One of the problems is the variation of performance of the same penetration grade from different producers. Such variation is also likely to occur under the new grading, but the more complete knowledge of the binder characteristics should make such behavior more predictable than less so and provide information to the contractor and buyer of any substantial change in asphalt supply that might affect construction operations and pavement performance.

Comments have been made in reference to the work of Lefebvre (8) showing differences in Marshall stabilities for materials of equal viscosity. However, this finding is in variance with findings in the Materials Division's laboratory for strength tests made by the Marshall and direct compression methods. Our studies show excellent correlation between viscosity of the binder and strength of the mixture for aggregates of the same type and gradation (7). Asphalts from several sources having widely different viscosity-temperature characteristics were used in these studies. The correlation was later confirmed by using viscosity-graded asphalts.

In summary, it can be said that the proponents of viscosity-graded specifications generally agree that such specifications will not automatically solve all the problems of asphalt construction or magically improve the quality of asphalt cements. However, in our opinion the advantages of such specifications outweigh the disadvantages, pro-

vided (a) that viscosity grading is supplemented by suitable controls on maximum consistency at low temperatures (indicated in the AASHO specification by penetration at 77 F) and (b) that proper attention is given to selecting the best grade for the environment and traffic. The specification proposed by AASHO is a national specification developed to include nearly all asphalts produced in the United States. Further study and experience might well show that some adjustment of limits or test requirements is necessary either on a national or on a regional basis. We strongly believe that the proposed AASHO specification represents the best balance that is now possible between conflicting needs and that its adoption by other specification agencies and universal use in construction specifications will mark a step forward for the asphalt industry.

REFERENCES

1. Welborn, J. Y., and Halstead, W. J. Absolute Viscosity as a Specification Control for Bituminous Binders. Public Roads, Vol. 31, No. 12, Feb. 1962.
2. Welborn, J. Y., Oglio, E. R., and Zenewitz, J. A. A Study of Viscosity-Graded Asphalt Cement. Public Roads, Vol. 34, No. 2, June 1966.
3. Halstead, W. J. Relation of Asphalt Ductility to Pavement Performance. Public Roads, Vol. 32, No. 10, Oct. 1963.
4. Hveem, F. N., Zube, E., and Skog, J. Proposed New Tests and Specifications for Paving Grade Asphalts. Proc. Assn. of Asphalt Paving Technologists, Vol. 32, Feb. 1963.
5. Welborn, J. Y., and Halstead, W. J. Properties of Highway Asphalts—Part I, 85-100 Penetration Grade. Public Roads, Vol. 30, No. 9, Aug. 1959.
6. Welborn, J. Y., Halstead, W. J., and Boone, J. G. Properties of Highway Asphalt—Part II, Various Penetration Grades. Public Roads, Vol. 31, No. 4, Oct. 1960.
7. Welborn, J. Y., Halstead, W. J., and Olsen, R. E. Relation of Absolute Viscosity of Binders to Stability of Asphalt Mixtures. Public Roads, Vol. 32, No. 6, Feb. 1963.
8. Lefebvre, J. A. Effect of Compaction on the Density and Stability of Asphalt Paving Mixtures. Proc. Canadian Technical Asphalt Assn., Vol. 10, Nov. 1965.

Discussion

L. C. KRCHMA, Mobil Oil Corporation—To a degree philosophical, there is no question that good asphalt pavement is a game of optimums. Pavement success and progress rest in doing the best we can with what we have at hand. A simple, thicker lift revolutionized compaction without demanding anything special in materials or equipment. Thus, good paving technology and full-depth design pavements give us unusual performance on the same basis. We should not take for granted the tremendous returns always gained with optimum asphalt contents. It is inescapable that pavement results and progress demand more of the same. This is the occasion for examining not the work reported here by Woody and York but whether grading asphalt cements at 140 F also represents an optimum such as the examples given.

For homework on a grading optimum, we offer the following as the controlling factors:

1. The nature of the crude from which asphalts are recovered primarily determines the character of asphalt. Processing methods are only secondary.
2. At the present state of paving technology, we are concerned with uniformity in application and in service. We are not at the point of any marked change in quality irrespective of whether we grade at 140 F.
3. Application temperature but not service temperature is subject to engineering control once a grade of asphalt is selected for a project.
4. Grading as practiced with asphalt is solely a tool to designate an asphalt of a given consistency. Its function is legal and commercial. Hence, safety, purity, and

durability (except as influenced by temperature susceptibility) are the same irrespective of grading system. It follows that additional selectivity among asphalts, where required, can only be obtained by tests and limits in addition to those used to grade the asphalt.

5. Service provided by today's asphalt pavements, with respect to both mileage and quality, was obtained with asphalts meeting 77 F graded specifications.

From these, grading issues are (a) uniform asphalt cement consistency at application and service temperatures and (b) asphalt cement economy, convenience, and availability. These are mutually incompatible but need consideration.

To obtain the uniformity referred to earlier, we have the following tools: (a) specification limits, (b) paving operation controls, and (c) choice of asphalt grade. These are mutually compatible and, hence, can help cope with the grading issues.

Concerning uniformity, from first principles, increasing differences between grading temperature and either service or application temperature results in increased variability.

This is shown in Figure 7, grading at 77 F, and Figure 8, grading at 140 F, for the same family of asphalts with identical differences in their temperature susceptibilities. Therefore, concerning asphalt service temperature consistency, on the average, uniformity is better at 32 F, for example, when graded at 77 F (distance AC, Fig. 7) than when graded at 140 F (distance AC, Fig. 8). Because the service temperature is below 140 F the majority of the time, 77 F is more representative of service conditions than 140 F. To get the same uniformity at such service temperatures with 140 F grading requires a more restrictive specification limit at temperatures other than 140 F. This would make it necessary to shrink the asphalt family by the shaded portion shown in Figure 9. (This is grading at 140 F, shown in Figure 8, drawn to make distance

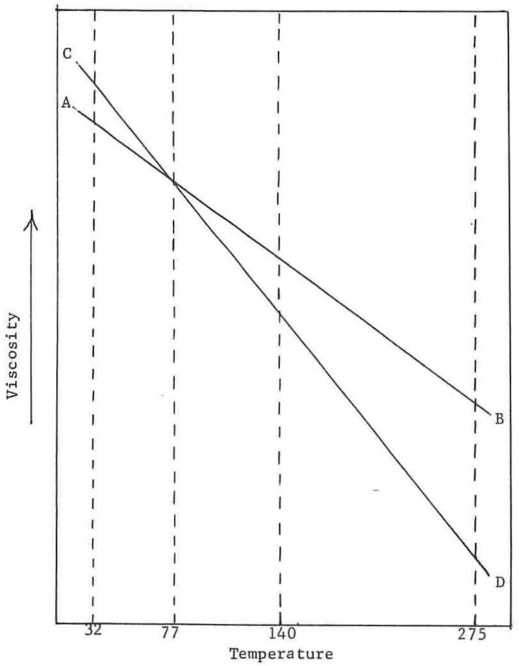

Figure 7. Service and application temperatures with 77 F grading; viscosity variabilities imposed by inherent temperature susceptibility differences among asphalts.

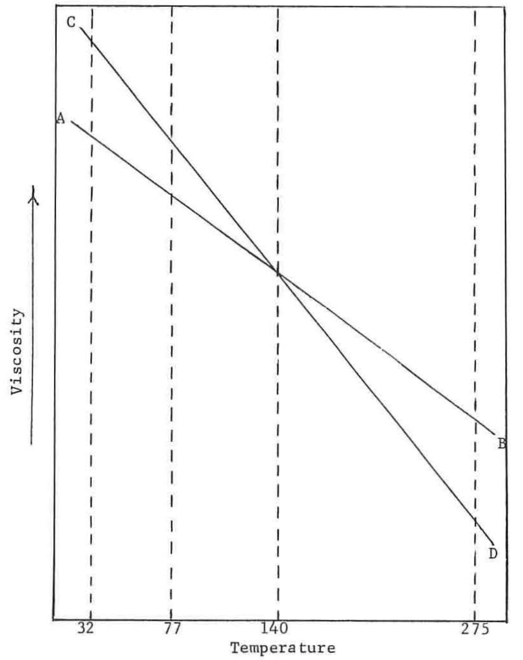

Figure 8. Service and application temperatures with 140 F grading; viscosity variabilities imposed by inherent temperature susceptibility differences among asphalts.

AC′ at 32 F equal to distance AC shown in Figure 7.) Hence, the alternatives open to grading at 140 F are more variable at service temperatures or more restrictive specifications. These do not represent the best use of materials at hand.

We can avoid these undesirable alternatives and associated complications when asphalts are graded at 77 F. With 77 F grading, it is possible to obtain more uniformity at service temperature. This feature is evident from a comparison of Figures 7 and 8. Then, uniformity at application temperature is gained by rational process controls by using available technology. So, we can get the best of both worlds: uniformity in both service temperature and application temperature areas.

Then, too, as McLeod shows, more attention to the selection of the asphalt grade promises even further performance uniformity where consistency at service temperature is critical. We may have been at fault in stressing the universal use of one grade such as the 85 to 100. It appears there are advantages to using both harder and softer grades, if we use them at their optimums.

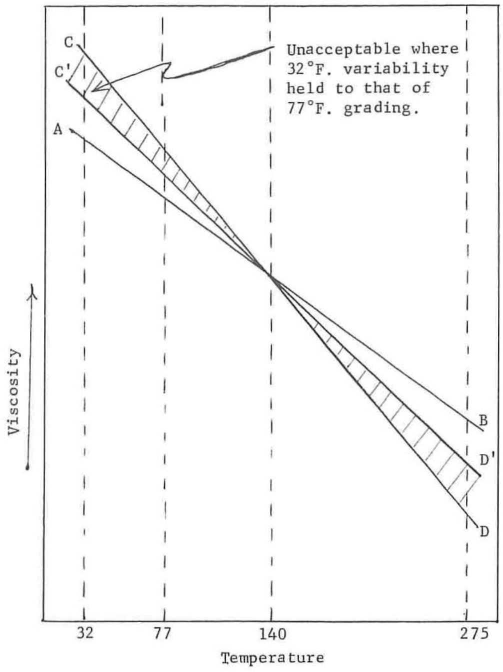

Figure 9. Reduction in acceptable 140 F graded asphalt temperature susceptibilities equaling 77 F grading service temperature-viscosity variabilities.

Further, the proper grading approach needs to be resolved. There are those who favor grading based on oven residues. Among other possibilities would be to grade by the temperature at which the asphalt is at some important service condition. Such grading might be more significant.

On the basis of this discussion, grading at 77 F plus good application information and its use in control plus some additional attention to grades best faces up to the significant issues. Further, it provides the best grading system, immediately available and recognized, to which other tests and limits can be added to increase the control of temperature susceptibility and durability as may be required in the future. These facts and possibilities bring 77 F grading closest to the optimum needed for good asphalt paving technology.

SOME ALBERTA EXPERIENCE WITH PENETRATION-GRADED ASPHALT CEMENTS HAVING DIFFERING VISCOSITIES AT 140 F

K. O. Anderson, University of Alberta; and
B. P. Shields, Research Council of Alberta, Edmonton, Canada

Experience in Alberta with 150 to 200 and 200 to 300 penetration grade asphalt cements has shown that those asphalts with low viscosities at 140 F are particularly susceptible to transverse cracking at low winter temperatures. This was verified in a carefully conducted paving project wherein three 200 to 300 penetration-grade asphalts representing low, intermediate, and high viscosities at 140 F were incorporated in the surfacing. The low viscosity section cracked earliest and most extensively and exhibited the most rapid densification under moderate traffic. Details of physical changes of the 3 asphalts during a 34-month service period are discussed. The tensile splitting test, conducted at 0 F, demonstrates the different strain capabilities of the 3 asphalts in order with their relative viscosities at 140 F. A general relationship among penetration at 77 F, absolute viscosity at 140 F, and tensile strain capability at 0 F is presented. A specification incorporating a minimum penetration of 250 at 77 F and minimum viscosity of 275 poises at 140 F was adopted in 1967. This has resulted in a more uniform product from provincial refiners, elimination of tender mixes, and a reduction in early transverse cracking.

•THERE is a great deal of controversy over the current approaches of grading asphalt cements according to penetration at 77 F or by absolute viscosity at 140 F. It is considered beyond the scope of this paper to attempt to present the various views, even by way of a brief summary; therefore, this paper will deal with information gathered from studies in our particular locale. This will necessarily limit direct application to the materials, construction procedures, load, and environmental conditions in Alberta; however, general conclusions may be considered valid for similar situations.

Until 1967, asphalt cements for use in highway construction were graded according to penetration at 77 F. Except for some early postwar pavements constructed in the late 1940's in which SC-6 materials were used, 200 to 300 or 150 to 200 penetration grade materials produced by as many as 10 different suppliers have been used through 1966. In 1967, a specification incorporating a viscosity requirement at 140 F was introduced by the Alberta Department of Highways. The grade most commonly used calls for a minimum penetration of 250 at 77 F and a minimum viscosity of 275 poises at 140 F, hence termed AC 275. Prior to this, variation in crude sources and refining methods of different suppliers resulted in asphalt cements of a given penetration grade that exhibited large differences in viscosity at 140 F. Extensive field performance surveys have been conducted on pavements built with these asphalt cements in which particular attention was given to the extent of transverse cracking exhibited under the low temperatures experienced in our western Canadian climate (1). These studies showed that the most extensive transverse cracking was associated with certain asphalt sources and that these sources usually had the lowest viscosity at 140 F. In order to bring the

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penetration-viscosity aspect into focus, the following discussion will be based primarily on field observations and related laboratory tests for a single paving contract in which 3 contiguous flexible pavement sections were constructed in 1966 by utilizing 200 to 300 penetration grade asphalt cements from 3 major refineries in Alberta. Details of this project have been reported elsewhere (2).

TEST PROJECT

During the summer of 1966, the Construction Branch of the Alberta Department of Highways undertook final asphaltic concrete paving of approximately 37 miles of 4-lane divided freeway in central Alberta within sections 2-D-2/1 and 2/2 of the highway system. In order to evaluate more precisely the possible environmental conditions contributing to low temperature transverse cracking and the influence of asphalt source, the department decided to incorporate within one 13-mile contract 3 different sources of 200 to 300 penetration grade asphalt cement. These 3 asphalt sources obtained from the major refiners in the province represented high, intermediate, and low viscosity materials, as measured at 140 F. It was felt that, within a single paving contract with uniform subgrade and base properties, it would be possible to obtain reasonably homogeneous, contiguous surfaces wherein the relative behavior of the asphalt cements could be evaluated. By careful planning, it was possible to change the asphalt supplier so that 1 source was present on one roadway and the other 2 sources abutted at a common point on the parallel roadway, satisfying the requirement that the 3 sources could be observed within an area where subsurface conditions would be uniform.

The pavement structure consisted of 4 in. of asphaltic concrete placed in 2 equal lifts on 2 in. of asphalt-bound base and 12 in. of compacted granular base. The asphaltic concrete surfacing was prepared from a single aggregate source within one contract; the sole major surfacing variable was the source of the asphalt cement.

TESTING PLAN AND PROCEDURES

Because the only major variable to be incorporated into the pavement surface was the source of 200 to 300 penetration grade asphalt cement, a comprehensive construction sampling and testing program was evolved. Three separate Marshall mix designs were prepared with the single source of aggregate to be used on the project. These are shown in Figure 1. They are similar in design characteristics, with the exception of stability where the mixture using the low viscosity asphalt cement exhibited a somewhat lower stability than the other 2 mixtures. The design mixes are generally of medium stability with somewhat low flow characteristics and low percentages of voids filled at optimum bitumen content.

Normal construction quality control procedures of the Alberta Department of Highways were maintained throughout the project. In addition, an extensive evaluation and testing program, primarily directed toward determining changes in the asphalt cement, was implemented. Because considerable time was involved in the procedures adopted, it was not intended that the construction process would be controlled by this method, but rather that reliance would be placed on the normal testing procedures undertaken for a project of this magnitude. Thus, the randomized test location procedure adopted involved single, composite samples for each phase of the mixing and placing process but did not involve replicate samples that would normally be used for preparation and application of statistically based quality control charts. In other words, the special testing program was designed to determine normally occurring quality variations. At each random testing time selected, usually at midmorning and at midafternoon when it was considered that plant operating conditions were stable, a sample of the bitumen supply was obtained immediately before entering the pug mill. The corresponding batch truck was noted, and a loose sample of the mix was obtained from behind the spreader on the road. Location and lift were recorded. Following completion of rolling, a minimum of three 4-in. diameter cores were obtained from the surface by using a diamond core barrel. Hot aggregate, mixture, and asphalt storage temperatures were obtained manually for each random sample, supplemented by air and mat temperatures at time of placing at commencement of breakdown rolling on the paving site. A total of 105

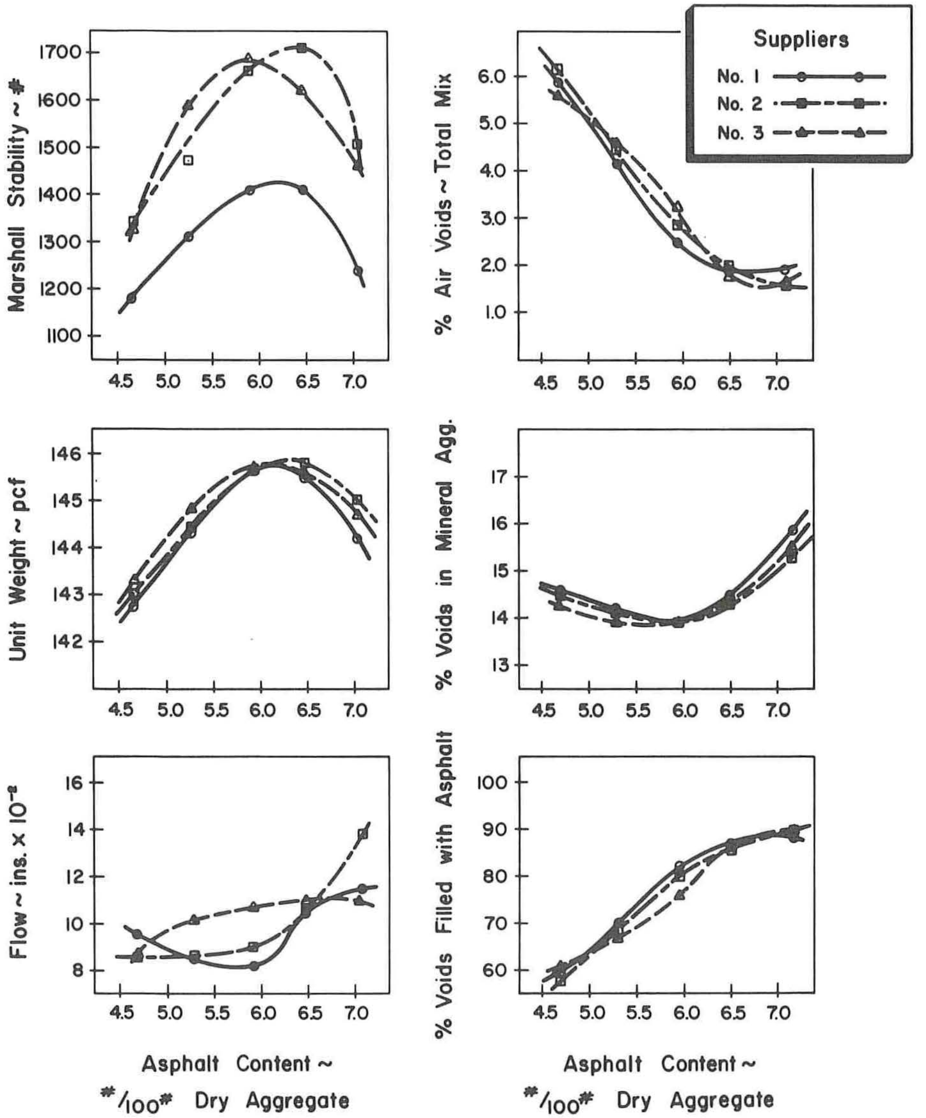

Figure 1. Marshall stability test results.

random test locations were sampled by this procedure during paving. Because of the large amount of laboratory work involved, it was necessary with some test procedures, particularly the thin-film oven test (TFOT) phase and subsequent testing of asphalt properties, to reduce the number of random samples tested; this was usually done by a subsequent random selection of a reduced number of samples for further testing.

RESULTS OF ASPHALT TESTING PROGRAM

The results of the bituminous testing program are given in Table 1 and shown in Figures 2, 3, and 4. The asphalt cement from supplier 1 was the most variable material supplied to the project, and in several cases samples exceeding 300 penetration were recorded. Supplier 2 provided the most uniform product. The intermediate vis-

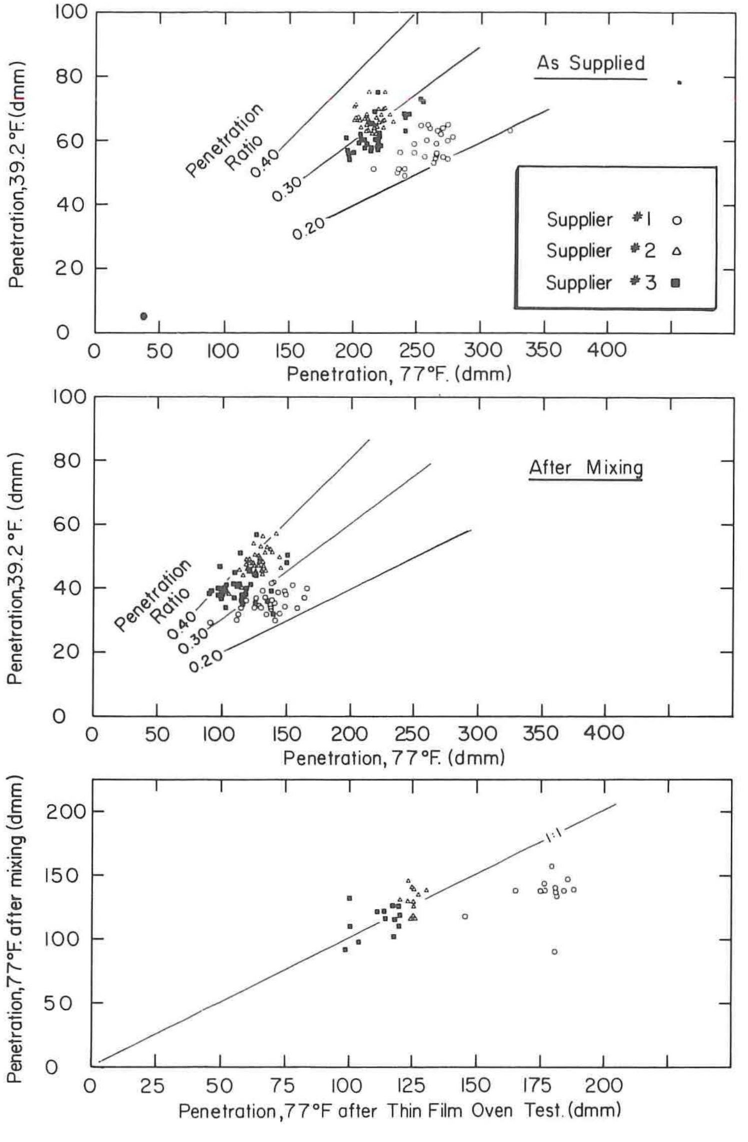

Figure 2. Penetration relationships.

cosity asphalt cement from supplier 3 exhibited somewhat more variability than that from supplier 2. The penetration relationships shown in Figure 2 indicate that suppliers 2 and 3 are roughly similar in terms of retained penetration both for the as-supplied condition and after extraction from the mix. The low viscosity asphalt cement (supplier 1) exhibited a lower retained penetration for both conditions. Figure 2 also shows that the TFOT appears to represent adequately penetration changes effected during mixing for suppliers 2 and 3. However, supplier 1 showed a marked deviation from this relationship. A similar relationship is evident in Figure 3, where the absolute viscosity at 140 F after TFOT is about twice the as-supplied viscosity for suppliers 2 and 3, and a somewhat smaller relative change occurs with supplier 1. A much higher variability in resultant viscosity after mixing is evident for suppliers 2

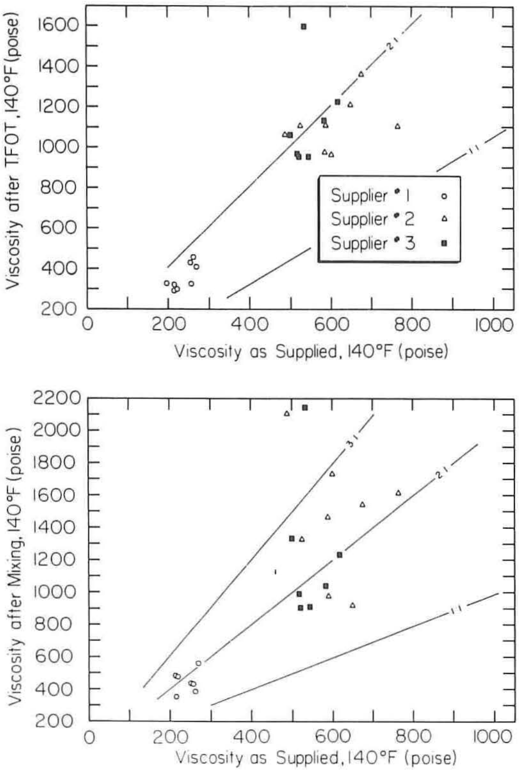

Figure 3. Viscosity relationships.

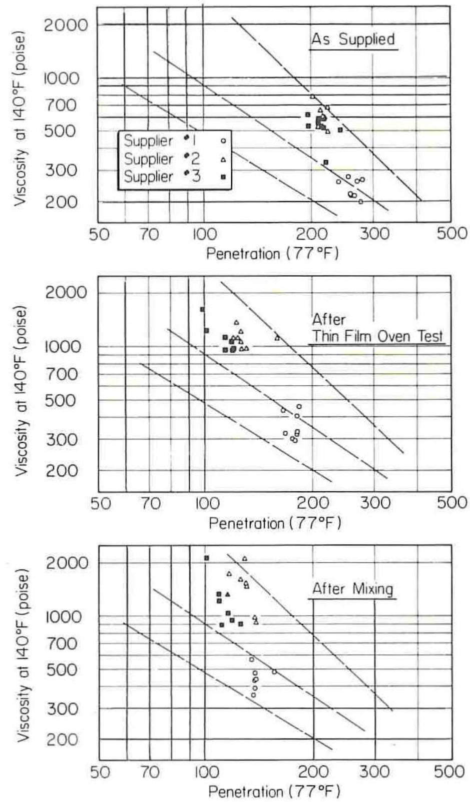

Figure 4. Relationships of penetration at 77 F and viscosity at 140 F.

and 3 as shown in Figure 3. It is evident that marked changes in the viscosity of these soft asphalt cements can occur through the normal mixing process, which is discussed in greater detail later; and it is also evident that, for the higher viscosity materials, the TFOT provides a reasonable indication of what viscosity changes might be expected. Figure 4 shows penetration at 77 F versus viscosity at 140 F for the 3 supplied materials from a smaller, randomized group of samples. Again it can be seen that supplier 1 occupies a lower level on the penetration-viscosity chart, and this remains consistent for the TFOT residues and for bitumen extracted from the plant mix.

FIELD CONSTRUCTION

Table 2 gives test results obtained on the finished surface. At each sampling location, whether lower course or upper course, a minimum of three 4-in. diameter cores were taken from the compacted mat, and densities determined in the laboratory. Bitumen contents and aggregate gradations were determined from the bulk sample obtained from the compacted mat. The pavement mixtures using asphalt from suppliers 1 and 2 appear to be rather similar (Table 2). Gradations in all cases were similar, as would be expected because the aggregate was produced from a single, large gravel pit. However, it will be noted that, for both suppliers 1 and 2, the average field density was just equal to 95 percent of Marshall density, which would suggest that approximately 50 percent of the finished pavement did not meet this specification level. With supplier 3 the major deviation from design was in the asphalt content; on the average approximately 1 percent asphalt less than the design recommendation was incorporated in the mixture, resulting in low densities and exceedingly high air voids. Variability in unit

TABLE 1

SUMMARY OF ASPHALT CEMENT QUALITY TESTS IN 1966

Supplier	Condition	Penetration (1/10 mm) 77 F	39.2 F	32 F	Softening Point[a] (deg F)	Viscosity 275 F (centistoke)	140 F[b] (poise x 10^0)	77 F[c] (poise x 10^5)	39.2 F[c] (poise x 10^8)	Penetration Index	Penetration Retained (percent)
1	Supply	265	68	40	103	139	237	3.0	1.2	+1.0	22.3
	σ	(28)	(8)	(4)	(7)	(8)	(26)				
	TFOT	177	43	22	108	—	358	8.6	2.5	+0.2	24.3
	σ	(12)	(7)	(2)	(1)		(60)				
	Mix	138	34	23	109	204	445	5.9	3.8	-1.0	25.3
	σ	(16)	(3)	(2)	(2)	(15)	(63)				
2	Supply	215	62	38	101	217	610	2.8	1.0	-1.0	31.2
	σ	(8)	(3)	(2)	(2)	(3)	(81)				
	TFOT	125	41	25	110	—	1,111	7.8	2.4	-0.8	32.8
	σ	(3)	(2)	(1)	(4)		(119)				
	Mix	113	41	27	111	309	1,415	13.4	3.4	-1.0	37.8
	σ	(9)	(4)	(2)	(3)	(20)	(350)				
3	Supply	217	58	35	102	184	544	2.3	0.8	-0.8	28.1
	σ	(15)	(4)	(3)	(2)	(10)	(36)				
	TFOT	112	38	24	110	—	1,127	24.3	2.0	-0.9	34.0
	σ	(7)	(1)	(1)	(1)		(212)				
	Mix	102	38	26	111	271	1,217	14.5	4.5	-1.3	36.3
	σ	(13)	(5)	(2)	(2)	(31)	(403)				

[a]ASTM D 36-26. [b]ASTM D 2171-66. [c]Sliding-plate microviscometer at shear rate of 10^{-2} sec^{-1}.

TABLE 2

SUMMARY OF ASPHALT CONCRETE QUALITY TEST IN 1966

Supplier	Condition	Bitumen Content (lb/100 lb)	Unit Weight (pcf)	Air Voids (percent)	Voids in Mineral Aggregate (percent)	Voids Filled (percent)	Gradation (percent passing) ¾ in.	No. 4	No. 10	No. 40	No. 200
1	Design	5.4	144.5	3.9	14.1	72.5	100	50	34	14	6.3
	Constructed	5.2	138.2	8.3	17.6	53.7	100	49.9	36.8	16.5	6.6
	σ	(0.46)	(4.5)	(2.1)	(1.4)	(9.0)	—	(2.9)	(1.9)	(1.7)	(0.8)
2	Design	5.4	144.6	4.2	14.1	70.5	100	51	34	15	6.8
	Constructed	5.3	136.7	9.5	18.8	49.1	100	51.1	37.6	14.8	5.8
	σ	(0.36)	(2.6)	(1.6)	(1.3)	(5.9)	—	(2.4)	(1.8)	(1.8)	(0.7)
3	Design	5.5	145.3	4.1	13.9	70.0	100	51	35	15	6.7
	Constructed	4.4	134.2	12.0	19.5	38.5	100	50.0	37.8	17.1	6.0
	σ	(0.43)	(2.4)	(1.7)	(1.3)	(5.4)	—	(3.7)	(2.4)	(2.6)	(1.2)

Note: n = 29 for supplier 1, 37 for supplier 2, and 39 for supplier 3.

weight and bitumen content was greatest with supplier 1; it will be noted, however, that with this low viscosity asphalt the highest initial densities were achieved.

The extensive quality variation studies carried out indicated that the objectives of the paving project were not met entirely. It was desirable to construct 3 uniform and similar paving mats, with the only variable the source of penetration grade asphalt cement used. However, because of unforeseen conditions, during construction the bitumen content was highly variable and was gradually changed from the beginning to the completion of the project. As a result asphalt cement from supplier 3 was placed at an asphalt content approximately 1 percent less than the suggested Marshall optimum, resulting in lower densities and higher air voids. Most other factors remained relatively constant and consistent, and it is not believed that the measured variations in gradation were particularly significant in terms of differences in mix properties.

CHANGES IN ASPHALT PROPERTIES IN SERVICE

Subsequent to completion in 1966, the test sections have been reexamined in the summers of 1967, 1968, and 1969 to determine changes in the characteristics of the asphalt and the asphaltic concrete in service. For the first 2 testing periods, approximately

TABLE 3

CHANGES IN ASPHALT PROPERTIES WITH TIME

Supplier	Age	Asphalt Content (percent)	Unit Weight (pcf)	Physical Properties of Asphalt Cement: Penetration ($^1/_{10}$ mm) 77 F	Penetration ($^1/_{10}$ mm) 39.3 F	Softening Point (deg F)	Absolute Viscosity at 140 F (poise)	Viscosity at 77 F (poise x 10^5) 10^{-3} sec^{-1}	Viscosity at 77 F (poise x 10^5) 10^{-1} sec^{-1}
1	As supplied			265	68	103	237	4.1	2.2
	After TFOT			117	43	108	358	17.9	4.1
	After plant mixing and spreading	5.2	138.2	138	34	109	446	15.9	4.0
	12 mo.	5.9	146.8	191	41	105	258	7.3	2.3
	24 mo.	5.75	146.6	196	44	102	258	2.8	2.0
	34 mo.	5.5	147.9	144	29	107	343		
2	As supplied			215	62	101	610	3.0	2.6
	After TFOT			125	41	110	1,111	9.2	6.7
	After plant mixing and spreading	5.3	136.7	113	41	111	1,460	22.5	7.8
	12 mo.	5.7	142.2	136	41	107	860	8.8	5.0
	24 mo.	5.4	143.1	127	38	107	954	6.2	4.9
	34 mo.	5.4	144.1	105	30	111	1,281		
3	As supplied			217	58	102	544	2.6	2.6
	After TFOT			112	38	110	1,127	12.1	10.2
	After plant mixing and spreading	4.4	134.2	102	38	111	1,217	15.2	8.6
	12 mo.	5.5	139.4	116	36	110	844	12.9	6.1
	24 mo.	5.3	141.6	90	28	113	1,215	11.7	10.6
	34 mo.	4.3	142.3	70	26	117	1,801		

ten 6-in. diameter cores were extracted from randomly selected outer wheelpath positions in the travel lane in each pavement section. Cores were subsequently trimmed and measured in the laboratory and extracted by the Abson process for determination of the characteristics of the recovered asphalt. The samples taken in 1969 were similarly selected and processed except that they were 4-in. diameter cores used for the tensile splitting test, discussed in more detail later. This information is given in Table 3 and compared with asphalt properties determined during the construction phase. Average penetration-viscosity relationships for the construction phase and for 2 in-service periods are shown in Figure 5. It is apparent that in-service asphalt properties determined 1 and 2 years after construction indicate less hardening of the asphalt cement than was indicated by the TFOT or from asphalt extracted from the uncompacted mix immediately before breakdown rolling (Table 3). This is indicated by higher retained penetrations and lower absolute viscosities at 140 F. There is fair agreement between penetration after the TFOT and penetration after 12 months of service, but the viscosities at 140 F are lower for in-service conditions than from the TFOT for all 3 asphalt sources. Regarding the results of extraction tests carried out on the material obtained from the uncompacted mix, it must be assumed that the sampling procedure (with a small amount of the batch being sampled immediately after spreading, without quenching in water) must have resulted in premature hardening of the asphalt.

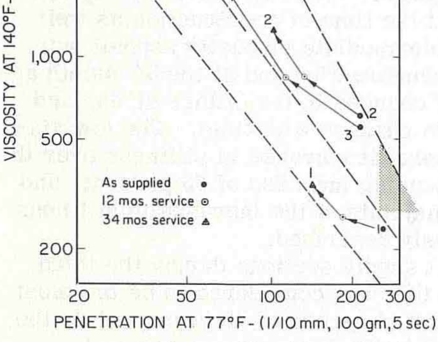

Figure 5. Penetration at 77 F versus viscosity at 140 F for various service ages.

Considerable differences exist between densities determined after final rolling (sampled

within 1 or 2 days) and those obtained at subsequent service periods. Calculations were made that indicated that densification by traffic after 2 years should have resulted in apparent rut depths of the order of 0.2 in., assuming uniaxial consolidation. However, rut depths measured at the end of the second year of service were only in the order of 0.06 to 0.10 in. (in other words between one-third and one-half the apparent densification as indicated by unit weight differences). As-compacted densities were determined from the average of three 4-in. diameter cores taken at each production unit location. Six-in. diameter cores were obtained at each sampling period in 1967 and 1968. All sets of cores were measured by identical procedures (uncoated immersion) in one laboratory so that the apparent density difference noted cannot be attributed solely to differences in measurement techniques. It is recognized that data obtained in service are from a relatively small sample, though all coring locations were randomized to avoid bias. For all 3 test sections, there is a significant difference between the as-constructed unit weight and the unit weight obtained from outer wheelpath samples after 24 months of service. There is no statistically significant difference between field densities obtained at 12 months and at 24 months of service. The largest increase in outer wheelpath density occurred with supplier 1, the low viscosity asphalt cement; and after 24 months, average air voids have been reduced to approximately 1.7 percent. An independent check on these changes in density is afforded by utilizing results of density measurements taken on the cores used for tensile splitting tests. Average densities in pcf at the time of construction and comparable values given in Table 3 (shown in brackets) are 138.6 (138.2), 137.0 (136.7), and 134.0 (134.2) for suppliers 1, 2 and 3 respectively. Average densities for cores taken at 32 and 34 months compared to the values given in Table 3 at 24 months (again shown in brackets) are 147.0 (146.6), 142.0 (143.1), and 141.4 (141.6).

Traffic during this period could be described as relatively light. The AADT in 1966 was 3,830 vehicles in both directions. This has increased to an AADT of 4,150 in 1969, with an estimated 15 percent or fewer trucks in the traffic stream.

RESULTS OF THE TENSILE SPLITTING TEST PROGRAM

Use of the tensile splitting test method for evaluating the response of asphalt concrete mixtures at low temperatures has been described in detail (3) and has formed a part of one of the specialized test programs in conjunction with this project. The slightly modified test method along with the computer analysis techniques available has been presented by Christianson (4) and illustrates how changes in low temperature properties can be observed.

A summary of tensile splitting test data at 0 F available for this project together with cracking frequencies is given in Table 4. Asphalt supplier 1, the low viscosity source, exhibits the greatest change in failure stress at the test temperature of 0 F. There is a 60 percent increase in failure stress over the period of time considered, compared to 6 and 30 percent for suppliers 2 and 3.

Failure strain, considered to be the most significant parameter of the tensile splitting test, also shows differing values for the 3 suppliers. The low viscosity asphalt cement, supplier 1, has the lowest failure strain at the time of construction as well as the 34-month service period. Supplier 3, the intermediate viscosity asphalt supplier, has the highest failure strain at the time of construction and at the 34-month age.

Failure stiffness reflects the combined effect of changes in the failure stress and strain and affords the use of a single term to denote changes with time. The low viscosity asphalt cement, supplier 1, exhibits a 185 percent increase in stiffness over the observed time period. Supplier 2 shows a corresponding increase of 33 percent, and supplier 3 shows an increase of 95 percent. The majority of the increase in stiffness may be attributed to the changes in density previously described.

The marked increase in cracking in all 3 asphalt supply sections during the third winter, 1968-69, may be explained by the fact that this was considered to be the most severe in central and northern Alberta for the period of record of 75 years, while the previous 2 winters were considered to be equivalent to the long-term average.

In reviewing the data presented, one can note that for this particular project observations to date indicate a definite correlation between the amount of low temperature

TABLE 4

SUMMARY OF TENSILE SPLITTING TEST INFORMATION ON HIGHWAY SECTIONS 2-D-2/1 AND 2/2 AT TEST TEMPERATURE 0 F

Supplier	Condition	Failure Stress (psi)	Failure Strain (in./in.)	Failure Stiffness (psi)	Pavement Performance (cracks/mile)
1	Design value	490	0.00074		
	At construction	302	0.00082	699,000	
	At 32 months	460	0.00056	1,679,000	
	At 34 months	505	0.00047	2,296,000	
	After first winter				4
	After second winter				87
	After third winter				187
2	Design value	480	0.00151		
	At construction	289	0.00105	599,000	
	At 32 months	305	0.00102	579,000	
	At 34 months	310	0.00061	1,071,000	
	After first winter				nil
	After second winter				nil
	After third winter				126
3	Design value	490	0.00165		
	At construction	194	0.00138	336,000	
	At 32 months	270	0.00083	623,000	
	At 34 months	263	0.00082	704,000	
	After first winter				nil
	After second winter				4
	After third winter				84

transverse cracking of asphalt pavements and failure stress, failure strain, and failure stiffness as measured by the tensile splitting test at 0 F. Comparing the sections constructed with the 3 sources of 200 to 300 penetration grade asphalt cement, we have made the following conclusions:

1. An increase in cracking frequency is accompanied by a decrease in failure strain and an increase in failure stress and failure stiffness;
2. An increase in density with service life is accompanied by a decrease in failure strain and an increase in failure stress, failure stiffness, and cracking frequency;
3. In terms of relative comparisons, the pavement section with the highest crack frequency also has the lowest failure strain and the highest failure stress and failure stiffness; and
4. In terms of service life, the low viscosity asphalt cement exhibits the greatest change in density, failure stress, failure strain, and failure stiffness and the highest cracking frequency per mile.

The previous observations were based on tensile splitting tests performed on core specimens. Therefore, construction variability must be considered in attempting to explain the low temperature response obtained. Subsequent to developing the method as a potential design procedure, information has been collected on a variety of mixtures using asphalt cements of varying penetration grades and viscosities. Figure 6 shows results based on laboratory specimens tested at 0 F and indicates failure strain values to be expected for various asphalt cements of differing penetration at 77 F and viscosity at 140 F. The contour lines have been drawn in tentatively on the basis of approximately 15 various mix designs and may have to be revised as more information becomes available. In the meantime, a basic point concerning the low temperature behavior of asphalt cements may be stated following an examination of data shown in Figure 6.

An increase in penetration value at 77 F, while maintaining the same relative viscosity at 140 F by paralleling lines A, B, or C, generally results in increased failure strain at 0 F. This is consistent with experience gained with the use of softer grades of asphalt cement in cold climates. It may be further noted that, for a particular pene-

tration at 77 F, an increase in viscosity at 140 F can be expected to produce large increases in failure strain at 0 F. This also reflects experience gained with low and high viscosity asphalt cements, but is not readily deduced from conventional asphalt tests at higher temperatures. Although a definite limiting failure strain cannot be stated at this time, indications are that values below 10×10^{-4} in./in. can be expected to indicate mixes having high potential for cracking under the climatic conditions of western Canada.

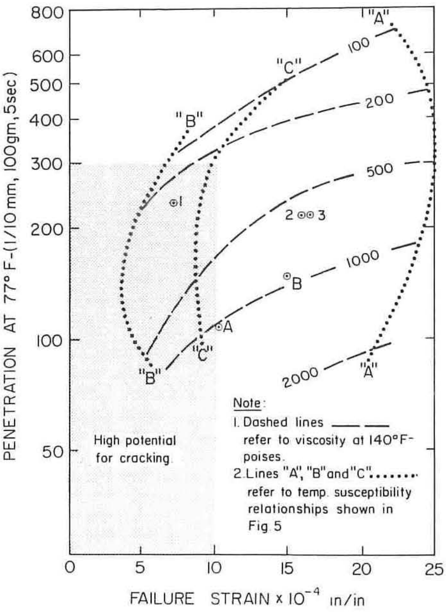

Figure 6. General relationship among tensile failure strain, penetration at 77 F, and viscosity at 140 F.

EXPERIENCE WITH VISCOSITY-GRADED ASPHALT CEMENTS

As noted earlier, in 1967 the Alberta Department of Highways revised its asphalt cement specifications to include a minimum acceptable viscosity at 140 F, basing this on extensive field surveys of low temperature cracking occurrence and the early performance of the test sections described in a preceding section (shown as shaded portion in Figure 5).

The change to specifying asphalt paving cements with a minimum value for viscosity and penetration has yielded some immediate improvements to the mixing and compaction phases of pavement construction. General field observations have shown that greater uniformity in mixing and rolling have been realized because of the smaller range of viscosity of asphalts obtained from various suppliers. This point is illustrated by the fact that contractors do not find it necessary to alter their rolling patterns because of a change in source of asphalt. There has been complete success in eliminating tender mixes that previously were experienced frequently.

These newly specified viscosity-graded asphalts have been in service for only 3 years. Performance during the first normal winter of 1967-68 was encouraging with only slight to no transverse cracking observed on most projects. However, the abnormally severe winter of 1968-69 resulted in large amounts of cracking in all projects constructed by using the new specification asphalt cements. A return to more normal conditions in the winter of 1969-70 again showed little initial crack development in the previous summer's construction.

The department's experience to date suggests that the specified minimum limits of 250 penetration at 77 F and 275-poise absolute viscosity at 140 F provide the softest asphalt that can be used under current surfacing criteria and requirements. The introduction of softer asphalts at this time would require major alterations in gradation to most provincial aggregate sources.

CONCLUSIONS

1. Extensive field surveys and laboratory investigations have shown that low temperature transverse cracking of flexible pavements in Alberta is closely associated with certain asphalt sources. These asphalt cements, penetration grades 150 to 200 and 200 to 300, are identified by a relatively low viscosity at 140 F.

2. A field experiment compared the in-service performance of 3 sources of 200 to 300 penetration grade asphalt cements ranging from low to high viscosity at 140 F. The low viscosity source exhibited the largest variation in conventional physical properties, most rapid densification under traffic, and the earliest and largest amount of low temperature cracking.

3. The tensile splitting test method can be used to measure the low temperature stiffness of asphaltic concrete mixtures; low temperature tensile strain capability increases with increasing viscosity at 140 F for a given penetration grade.

4. A specified minimum viscosity at 140 F for soft penetration grade asphalt cement has resulted in a more uniform product from several distinct sources, the elimination of tender mixes, and an apparent reduction in low temperature transverse cracking, under normal winter conditions.

REFERENCES

1. Anderson, K. O., Shields, B. P., and Dacyszyn, J. M. Cracking of Asphalt Pavements Due to Thermal Effects. Proc. Assn. of Asphalt Paving Technologists, Vol. 35, 1966.
2. Shields, B. P., Anderson, K. O., and Dacyszyn, J. M. An Investigation of Low Temperature Cracking of Flexible Pavements. Proc. Canadian Good Roads Assn., Ottawa, 1969.
3. Anderson, K. O., and Hahn, W. P. Design and Evaluation of Asphalt Concrete With Respect to Thermal Cracking. Proc. Assn. of Asphalt Paving Technologists, Vol. 37, 1968.
4. Christianson, R. H. A. Analysis of the Tensile Splitting Test for Low Temperature Tensile Properties of Asphaltic Concrete. Master of Science thesis, University of Alberta, Edmonton, 1970.

VISCOSITY GRADING FOR ASPHALT CEMENTS

John Skog and George Sherman, Materials and Research Department,
California Division of Highways

The development of tests for measuring consistency of paving-grade asphalts in the range of 40 to 325 F has led to the development of specifications for specifying grade requirements at 140 F. The purpose of these requirements is to provide uniformity in asphalt viscosity during placement and rolling operations and in service resistance to rutting. It is well known that paving-grade asphalts change in viscosity during mixing operations and that asphalts from different sources change at different rates under the same conditions. Results presented show that a series of asphalts having original viscosities at 140 F within a narrow band had a very wide range in viscosity after a test that simulates hot-mix hardening. Studies on the relation between asphalt consistency and field "setting" properties of the paving mixture are presented. These studies involved the use of 6 paving-grade asphalts on one contract. The field setting properties showed a good correlation with the recovered asphalt viscosity at 140 F. The best correlation coefficient with the recovered asphalt viscosity is the viscosity at 140 F after tests simulating mixing, namely the standard thin-film oven test or the rolling thin-film oven test.

•PAVING-GRADE asphalt is a thermoplastic material. This very important property of this adhesive makes it possible to coat aggregate particles at elevated temperature and to spread and properly compact the resulting mixture to form a pavement. On the other hand, this same property may lead to detrimental increases in viscosity of the binder at low temperatures with failures caused by cracking of the pavement.

The change in consistency with temperature has been termed "temperature susceptibility" by asphalt technologists, and a great amount of research has been expended in developing test methods for measuring consistency over the broad range of temperatures encountered in the use of paving-grade asphalt. Methods have been developed to measure consistency in absolute units over a temperature range from below 40 to 325 F. However, not all of these methods are useful for control testing, especially below 77 F.

We presently measure temperature susceptibility of the asphalt at completion of manufacture. Many tend to ignore the fact that the consistency at any specified temperature and the slope of the temperature-susceptibility line change during mixing, laying, and service life. This means that asphalts weathering in the field at even a normal rate may have low-temperature characteristics completely different from those found immediately after manufacture. Because different asphalts weather at different rates under identical field conditions, the rate of change of their low-temperature characteristics will also vary even though they may all have equivalent characteristics after manufacture. It is, therefore, logical to conclude that the original temperature-susceptibility curve does not provide sufficient information of value in determining the service life viscosity-temperature relationships of the binder.

The paving engineer first becomes interested in the properties of the binder at the time of application to the aggregate in the mixer box. It is important that a properly coated mixture be attained, and consistency at the mixing temperature is a critical

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factor. His next interest is in the laying and compaction of the mixture. It is well known that the consistency in the range of compaction temperatures (breakdown, pneumatic, and finish rolling) will influence the densification process. Further problems involving setting of the paving mixture following compaction are partly influenced by the consistency of the binder at the time of and following compaction. This paper will present a laboratory and field study on viscosity grading after a test that simulates hot-mix hardening.

CONSISTENCY AND THE SETTING PROBLEM OF ASPHALT CONCRETE

"Certain types of paving mixtures may be difficult to compact properly and after rolling may remain 'tender' for periods of up to two weeks. The 'tenderness' of the pavement immediately after construction produces problems when traffic must be carried through the work" (1).

Studies by the California Division of Highways indicate that one of the factors influencing the setting properties of a paving mixture is the consistency of the asphalt during placement and rolling. Previous studies (1) indicate that an asphalt viscosity range of 4,000 to 6,000 poises at 140 F will provide a satisfactory asphalt. This is based on field correlation involving currently used 85 to 100 grade asphalt. Independent studies by Schmidt and associates (3) have confirmed these requirements.

It is important to note that our studies as well as those of Schmidt are based on the actual viscosity of the asphalt in the paving mixture. This viscosity at any specified temperature will be different from the value for the asphalt as manufactured. Further, the rate of change is different for asphalts from different sources. This is shown in Figure 1, which shows the viscosities of residues from the rolling thin-film oven test (RTFOT), a test that simulates hot-mix hardening. We note that this series of asphalts was manufactured to comply to the AC-20 grade, which has a relatively narrow band for the viscosity at 140 F. However, after the RTFOT, the range in viscosity at 140 F is 4,500 to 12,000 poises. It appears that the asphalts in this group will provide different degrees of "set" in the same paving mixture.

Either the RTFOT or the AASHO standard thin-film oven test (STFOT), developed by the Federal Highway Administration, may be used for simulating the mixing operation. Hveem et al. (1) and Skog (2) show a good correlation between these 2 tests. Further, Hveem et al. (4) showed an excellent correlation between the STFOT results and hardening during mixing. This confirms previous work by the Federal Highway Administration. The RTFOT was also independently correlated with field-mix hardening (1, 2).

Further field studies, subsequent to publications of reports by Hveem (1) and Skog (2), have been performed in the attempt to confirm previous findings on the importance of the viscosity parameter in field setting. The most important of these test sections was one placed on a road through the desert area of southern California during June 1967. This test section was placed as part of contract 08-039334, road 08-SBd-40-R28.4/42.1, and as part of a Federal Highway Administration's proposal to study field performance of viscosity-graded asphalts.

A number of California-produced asphalts with fairly wide ranges in viscosity for a constant penetration and a range in penetration for a constant viscosity were chosen for study. Also 2 special asphalts manufactured in connection with a California tentative specification (2) were included.

The original viscosity-penetration relationships for these asphalts are given in Table 1, and the viscosity results after

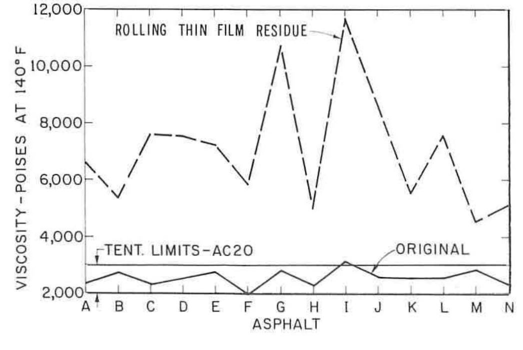

Figure 1. Change in kinematic viscosity after California RTFOT, AC Series, Grade AC-20.

TABLE 1

ORIGINAL VISCOSITY-PENETRATION RELATIONSHIPS

Asphalt	Grade	Penetration at 77 F	Viscosity at 140 F
1	AC-12	84	1,102
2	AC-12	119	1,029
3	85 to 100	90	1,471
4	85 to 100	80	1,042
5	Special	75	1,734
6	Special	107	1,067

TABLE 2

VISCOSITY RESULTS AFTER THIN-FILM OVEN TESTS

Asphalt	Grade	Viscosity at 140 F	
		RTFOT	STFOT
1	AC-12	1,801	1,889
2	AC-12	2,884	3,273
3	85 to 100	3,955	4,545
4	85 to 100	2,397	2,881
5	Special	4,346	4,316
6	Special	2,688	2,767

the RTFOT and the STFOT are given in Table 2. All asphalts were used in a California Standard Specification Type A, $\frac{3}{4}$ in., medium-grading mix. The resulting mix was spread and rolled with equivalent equipment. Test sections containing asphalts 1, 2, 3, and 4 were paved on one day and asphalts 5 and 6 about 3 weeks later. In all cases the weather was dry and fairly warm, 66 to 100 F, with morning temperatures of 66 to 87 F.

Setting of the paving mixture containing the various asphalts was judged by observation during rolling and by asking the opinion of the breakdown roller operators. Asphalt 1 was the only asphalt that showed definite signs of slow setting. There was "sticking" to both the breakdown and pneumatic rollers, and the roller operators complained that the mix felt "mushy." There was a tendency for the roller operators to "lay back" in attempting to roll the mixture. None of these observations was noted with asphalts 2, 3, 4, 5, and 6. The same roller man commented that asphalt 5 rolled out in an excellent manner.

The field setting ratings compared with the original viscosity, viscosities after tests simulating the mixer hardening, and recovered asphalt from mix immediately after mixing are given in Table 3. Also given in the table are the original and recovered penetration results. We note the good correlation between the recovered asphalt viscosity at 140 F and the field setting properties. The best correlation coefficient with the recovered asphalt viscosity is the viscosity after tests simulating mixing, the standard and rolling thin-film oven tests (Table 4).

Other field trials appear to indicate that an asphalt having a viscosity range, after a simulated mixer hardening test, of 3,500 to 5,500 poises at 140 F and a viscosity range of 300 to 700 centistokes at 275 F should provide paving mixtures of satisfactory setting qualities during paving under high atmospheric temperatures. One of the real advantages of this proposal is the uniformity of asphalt viscosity during laying and compaction. It also permits the producer to start with a harder or softer grade in order to make an asphalt of common viscosity range during paving operations.

The proposal to grade asphalts at elevated temperatures either in the original state or after tests that simulate mixer hardening has been criticized on the basis that con-

TABLE 3

COMPARISON OF PENETRATION AND VISCOSITY RESULTS WITH FIELD SETTING EVALUATION

Asphalt	Grade	Original Penetration at 77 F	Viscosity at 140 F			Abson Recovery Test Results		Field Setting Evaluation
			Original	After STFOT	After RTFOT	Penetration at 77 F	Viscosity at 140 F	
1	AC-12	84	1,102	1,889	1,808	59	2,014	Slow
2	AC-12	119	1,029	3,273	2,884	68	3,732	Satisfactory
3	85 to 100	90	1,471	4,545	3,955	47	4,909	Fast
4	85 to 100	80	1,042	2,881	2,397	50	2,914	Satisfactory
5	Special	75	1,734	4,316	4,346	50	5,165	Fast
6	Special	107	1,067	2,767	2,688	66	3,136	Satisfactory

trol is lost over low-temperature consistency. This may be responsible for cracking of asphalt concrete pavements under low-temperature conditions.

We are in agreement that some form of low-temperature consistency requirement is needed and that the currently used penetration test at 77 F is the best test available for routine control. However, we also believe that there is a need for a minimum penetration after a test that simulates hot-mix hardening. This will provide an effective means to prevent the manufacture of asphalts that comply with elevated viscosity requirements but that have high temperature susceptibility leading to very high viscosities at low temperature.

TABLE 4

CORRELATION COEFFICIENTS

Item	Recovered Viscosity	Recovered Penetration
Viscosity		
Original	0.833	0.648
After STFOT	0.985	0.546
After RTFOT	0.992	0.491
Penetration, original		0.834

In summary, the paving engineer should be provided with asphalts that are within a uniform range of consistency during laying and compaction operations. We believe that this can only be done by specifying consistency measurements on the asphalt after it has been subjected to simulated hot-mix hardening.

ACKNOWLEDGMENTS

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

REFERENCES

1. Hveem, F. N., Zube, E., and Skog, J. Proposed New Tests and Specifications for Paving Grade Asphalts. Proc. Assn. of Asphalt Paving Technologists, Vol. 32, 1963, p. 271.
2. Skog, J. Setting and Durability Studies on Paving Grade Asphalts. Proc. Assn. of Asphalt Paving Technologists, Vol. 36, 1967, p. 387.
3. Santucci, L. E., and Schmidt, R. J. Laboratory Methods for Grading Setting Qualities of Paving Asphalts. ASTM, Symposium on Grading of Paving Asphalts by Viscosities at 140 F Versus Penetrations at 77 F, Atlantic City, June 1966.
4. Hveem, F. N., Zube, E., and Skog, J. Progress Report on the Zaca-Wigmore Experimental Asphalt Test Project. ASTM, Spec. Tech. Publication 277.

TEMPERATURE-SUSCEPTIBILITY CONTROL IN ASPHALT-CEMENT SPECIFICATIONS

H. J. Fromm and W. A. Phang, Department of Highways, Ontario

The introduction of some waxy asphalt cements into Ontario in the early 1950's caused some serious construction problems where these products were used. The problem was one of temperature susceptibility where the asphalt cements became very thin at high temperatures. This caused problems with drying and in laying and compacting the mix. A solution to the problem has been obtained by controlling the temperature susceptibility with a 2-point consistency specification. This consists of a minimum viscosity specification at 275 F in addition to the normal penetration at 77 F. The minimum specifications are above those recommended by The Asphalt Institute. Relationships have been determined between penetration at 77 F and viscosities at 77, 140, and 275 F for asphalt cements currently supplied in Ontario. A new criterion for low-temperature performance, critical temperature, T_c, is introduced. This is an indication of the low-temperature flow properties of the asphalt mix. A method is also suggested for the selection of a suitable asphalt-cement grade for various low temperature environments by using stiffness modulus.

•THE CONSISTENCY specifications for asphalt-cement grades have been written for half a century in terms of the penetration test (1), and much engineering data and experience have been accumulated regarding asphalts and road construction in terms of this test. Provided that asphalt properties remain reasonably consistent from one crude source to another, the penetration test is quite sufficient to specify consistency. With the introduction of many waxy crudes, however, this test alone is no longer adequate for controlling the desired consistency of asphalt cements.

A single-point consistency specification merely provides a pivot about which the viscosity (consistency)-temperature line may rotate when changes are made in the type of crude oil used. With the more temperature-susceptible asphalt cements, this line slopes more sharply upward, so that these asphalts are less viscous at the temperature used for road construction and much more viscous and brittle at low winter temperatures.

Within the past few years it has been suggested that asphalt cements should be specified by a viscosity range at 140 F rather than by a penetration range at 77 F. This change has been sponsored by several organizations, including The Asphalt Institute (2). One fact in favor of this move is that a fundamental property is specified rather than an arbitrary number, as is the case with the penetration test. The values obtained in the penetration test are influenced not only by the consistency of the asphalt cement but also by its composition. One of its ingredients, paraffin wax, has a marked effect in this test (3, 4). The adoption of viscosity grading of asphalt cements at 140 F would not, however, solve the problem of the more temperature-susceptible asphalts. This problem can only be solved by using a consistency specification that controls the temperature ranges at 2 or more different temperatures in order to limit the slope of the viscosity-temperature line. The current Asphalt Institute specification for asphalt

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cements lists a minimum viscosity at 275 F for each grade in addition to the regular consistency requirement (5). In the authors' opinion, these minimum viscosities are set much too low. The problem of eliminating the more temperature-sensitive asphalt cements and their attendant problems has been solved in Ontario by specifying a higher minimum viscosity at 275 F for each grade in addition to the normal penetration range.

ASPHALT-CEMENT SPECIFICATIONS

The current (1970) asphalt-cement specifications of the Department of Highways, Ontario, are given in Table 1. The first listed (60 to 70 penetration grade) is not used by the department but is included in the specifications for the convenience of the municipalities who quote Ontario specifications when ordering asphalt cements. The 85 to 100 and 150 to 200 penetration grades have been used by the department for many years, the former in the southern part of the province and the latter in the northern areas. The final grade given in Table 1 (300 to 400) was first specified in 1968 and is being used experimentally in an attempt to reduce the transverse cracking occurring to pavements in the northern part of the province. Several changes have been made to these specifications since 1956: changes were made in the thin-film oven test; the ductility at 77 F requirement was deleted in 1961 in favor of a ductility at 39.2 F; the ring-and-ball softening point was deleted at the same time; and the solubility in carbon tetrachloride was changed in 1970 in favor of one in trichloroethylene. The penetration ranges and the minimum flash points, however, have remained unchanged. The major changes have taken place in the viscosity specifications, which were nonexistent in 1956. These changes and the reasons for them are outlined in the following section.

VISCOSITY SPECIFICATIONS

The viscosity requirements incorporated into the department's asphalt-cement specifications resulted from the temperature-sensitive asphalt cements that were introduced into the province. The problems associated with these asphalt cements were first experienced in Ontario during the mid-1950's. The source of the problem was unknown initially, but construction difficulties appeared where certain types of asphalt cements were used. The source of the difficulties was later recognized as high temperature sensitivity. The situation was further complicated because asphalt cements,

TABLE 1

ONTARIO ASPHALT-CEMENT SPECIFICATIONS IN 1970

Specification Designation Requirements	60 to 70 Penetration		85 to 100 Penetration		150 to 200 Penetration		300 to 400 Penetration		ASTM Test Method (latest revised standards)
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
Flash point, COC, deg F	450	—	450	—	425	—	350	—	D 92
Penetration at 77 F, 100 g, 5 sec.	60	70	85	100	150	200	300	400	D 5
Kinematic viscosity at 275 F, centistokes	360	—	280	—	200	—	120	—	D 2170
Thin film oven test, 50 g, 325 F, 5 hr									
Percent loss in weight	—	0.80	—	0.85	—	1.3	—	1.3	D 1754
Percent retained penetration at 77 F	52	—	47	—	42	—	35	—	D 1754
Ductility of residue at 77 F, cm	50	—	75	—	100	—	100	—	D 113
Ductility at 39.2 F, 1 cm/min	4	—	6	—	10	—	15	—	D 113
Solubility in trichloroethylene, percent	99.5	—	99.5	—	99.5	—	99.5	—	D 2042

of both high and low temperature sensitivity (Venezuela and Mid-East crudes), were being used in the province.

The difficulties experienced with the temperature-sensitive asphalts were briefly as follows:

1. When hot mixes were produced at normal temperatures (275 to 300 F), these asphalt cements produced very fluid mixes that were hard to lay and compact. The mixes had slow setting times, and intermediate and finishing rollers had to be withheld 2 or 3 hours behind the paver. This increased construction costs. In one instance, the mix was unable to withstand normal truck traffic near the edge of the new pavement even several days after placement. In another case, the hot mix tore into small fissures directly behind the paver screed, producing a washboard pavement when compacted. These problems were resolved when the asphalt cement used in the mix was changed to one of lower temperature sensitivity. In other cases, a filler of ground limestone had to be added to the mix to speed up the setting time. Both of these actions had the effect of increasing the asphalt mix viscosity.
2. If the temperature at which the mix was produced in the asphalt plant was reduced to provide a more workable mix, aggregate drying problems were encountered. It was sometimes necessary to double-dry the aggregates (2 passes through the drier with a holding period between them) to produce the desired laying characteristics of the mix.
3. Pavements constructed with temperature-sensitive asphalt cements had a greater tendency to flush than those produced with less temperature-sensitive asphalt cements. Two different test pavements were laid by using the 2 types of asphalt cements, both of the same penetration grade. In both cases the more temperature-sensitive asphalt cements flushed after the first year. This resulted from the increased mobility of the cement under the summer temperatures and traffic volumes, which caused the asphalt cement to creep to the surface of the pavement.
4. Some pavements constructed with these temperature-sensitive asphalt cements exhibited very severe transverse cracking after only a few winters of use, suggesting that they were more brittle at low winter temperatures than the less temperature-sensitive cements.

A study of the viscosity at 275 F of all asphalt cements was undertaken. This disclosed that, of the 85 to 100 penetration asphalt cements, those that performed well had lower temperature sensitivity and viscosities (at 275 F) in the range of 360 to 460 centistokes, while those causing problems had viscosities in the range of 160 to 220 centistokes. For the 150 to 200 penetration cements, the problem group had viscosities around 120 to 160 centistokes, while the others had viscosities around 240 to 300 centistokes. It was also noted that, in the case of the 85 to 100 penetration cements, the ductility at 39.2 F was low (6 to 12 cm) for the temperature-sensitive asphalts and 15 cm or more for the less temperature-sensitive asphalt cements. This was taken to be indicative of greater hardening at low temperatures of these temperature-sensitive asphalt cements.

As a result of this investigation, specifications for viscosity were imposed that increased each year for 3 years until they reached the current levels in 1963. For the 85 to 100 penetration asphalt cements, the minimum viscosity at 275 F was set at 170 centistokes in 1961, raised to 190 in 1962 and finally set at 280 in 1963. For the 150 to 200 penetration asphalt cement, the minimum viscosity was set at 190 centistokes in 1962 and raised to 200 in 1963. When the 300 to 400 penetration cement was introduced in 1968, the minimum viscosity at 275 F was set at 140 centistokes. Some suppliers found this requirement impossible to meet and it was reduced to 120 centistokes in 1970. The latter value is more realistic and in accord with the viscosity specifications for other grades.

At the beginning of this investigation, it was observed that asphalt cements within a given grade that had low viscosity values at 275 F also had lower ducility values at 39.2 F. A ductility specification was, therefore, imposed at this temperature and the 77 F ductility requirement (which all cements always pass easily) was deleted to ensure that the material had some ductility at low temperatures. The minimum value

was set in 1961 at 8 cm for the 85 to 100 grade and 12 cm for the 150 to 200 grade. Current values used since 1963 are 6 and 10 cm respectively.

In order to compare the penetration grading of asphalt cements supplied to the department with what might be obtained on a viscosity grading at 140 F, several selected asphalt cements were tested during the past 2 years for viscosity at different temperatures. The results of these tests are given in Table 2. The first column of the table lists the suppliers and, because a supplier may produce asphalt from several different locations, these were identified as A1, A2, and so on. The viscosities at 77 F were determined by using a sliding-plate microviscometer at a shear rate of 5×10^{-2} sec^{-1}. The viscosities at 140 F were measured with a vacuum-capillary Koppers tube, and the viscosities at 275 F were measured with a Zeitfuchs cross-arm viscometer.

ANALYSIS OF RESULTS

One of the chief arguments against grading asphalt cements by viscosity at 140 F has been the wide range of penetration values that can be associated with each viscosity grade. This is due to the varying temperature susceptibilities of the different asphalt cements. This point has been discussed by McLeod (6) and is shown in Figure 1 (6, 7). When the data given in Table 2 were plotted in a similar manner, the result shown in Figure 2 was obtained. In this instance, there is much less scattering of data, despite the fact that 10 sources were concerned and both Canadian and imported crude oils were used to produce the asphalt cements. Superimposed on this graph are 3 lines showing the viscosity-penetration relationship of asphalt cements with penetration indexes (PI) of 0.0, -1.0, and -1.5. These lines were calculated by Lefebvre (8). It will be observed that there is a clustering of data for each grade of asphalt, rather than a spread-out pattern as shown in Figure 1. This is because the temperature susceptibility has been controlled within prescribed limits by the use of a minimum viscosity specifica-

TABLE 2

CONSISTENCY TESTS ON ONTARIO ASPHALT CEMENTS

Supplier	Penetration at 77 F	Viscosity at 77 F (poises)	Viscosity at 140 F (poises)	Viscosity at 275 F (centistokes)	Supplier	Penetration at 77 F	Viscosity at 77 F (poises)	Viscosity at 140 F (poises)	Viscosity at 275 F (centistokes)
A1	62	2.12×10^6	2,736	461	C3	81	1.12×10^6	1,389	346
	60	2.93×10^6	2,485	465		91	1.14×10^6	1,457	329
	56	2.35×10^6	2,636	453		88	9.25×10^5	1,217	328
	81	1.07×10^6	1,426	338	D1	65	1.35×10^6	2,600	450
	90	1.14×10^6	1,415	340		89	1.25×10^6	1,698	377
	94	7.80×10^5	1,436	332		93		1,450	340
A2	86	9.60×10^5	1,809	410		142		797	265
	90	9.00×10^5	1,609	403		180	2.73×10^5	607	240
	98	9.21×10^5	1,710	402		167	2.25×10^5	625	230
	158	2.75×10^5	687	270		373	6.04×10^4	188	142
B1	155	3.00×10^5	632	236		342		250	146
	160	3.20×10^5	567	231	D2	67	3.6×10^6	4,756	536
	364	5.26×10^4	247	146		86	7.35×10^5	1,414	315
	180	1.95×10^5	509	209		87	8.7×10^5	1,562	355
B2	94	8.35×10^5	1,395	348		93	1.0×10^6	1,612	352
	155	3.10×10^5	502	244		178	1.48×10^5	583	220
	169			247		173	2.90×10^5	801	237
	155	2.60×10^5		241		168	1.95×10^5	634	217
	287	9.8×10^4	286	163		410		200	143
	303			159	E1	65	1.53×10^6	2,661	490
C1	93		1,545	349		95	9.70×10^5	1,419	360
	98	9.00×10^5	1,445	334		90	9.6×10^5	1,388	361
	96	9.00×10^5	1,566	338		95	9.3×10^5	1,437	351
	172	3.26×10^5	642			195	2.36×10^5	505	224
	160	3.09×10^5	725	240		180	2.20×10^5	510	228
	153	2.53×10^5	661	245		179	2.0×10^5	551	242
	379	6.12×10^4	216	138		381	7.56×10^4	231	156
	370	7.00×10^4	223	138		195	2.36×10^5	505	224
	361		227	154		349	7.35×10^4	234	159
C2	187	2.00×10^5	604	231		373	5.05×10^4	218	158
	188	2.21×10^5	585	230					
	164	2.32×10^5	657	240					
	373		223	138					

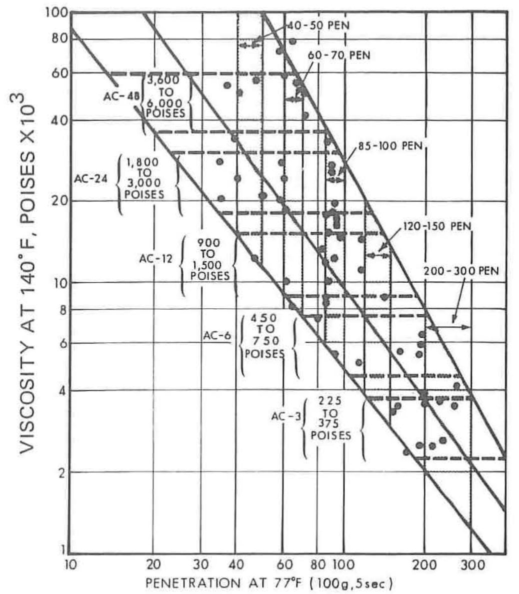


Figure 1. Correlation between viscosity at 140 F and penetration at 77 F for currently used asphalt cements (6).

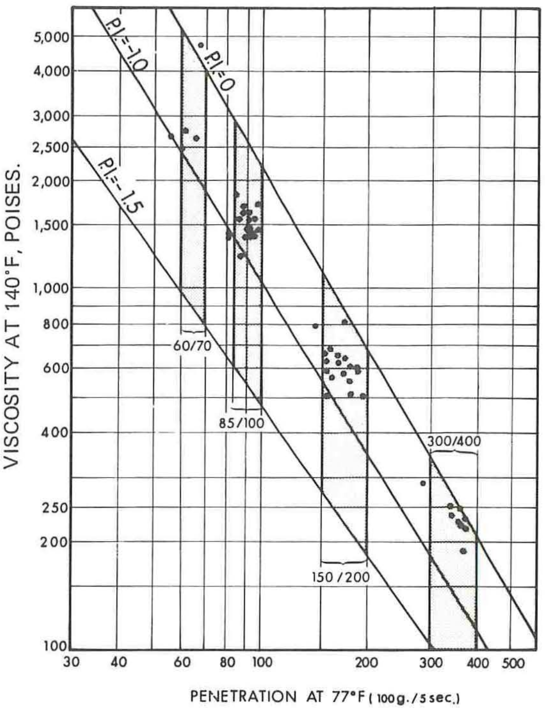


Figure 2. Viscosity at 140 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

tion at 275 F. This specification has nearly eliminated all asphalt cements with PI of less than -1.0. An upper value of viscosity has not yet been specified at 275 F because nearly no asphalt cements with a PI of more than 0 are available in Canada.

The relationship between viscosity, in poises, at 77 F and penetration at 77 F is shown in Figure 3. The line drawn through the plots is the linear regression line, and the dotted lines on either side of it are the 95 percent confidence limits. The equation of the regression line is

$$\log V = 9.889 - 2.00 \log P$$

where

V = the viscosity in poises at 77 F, and
P = the penetration in 0.1 mm at 77 F;

or this may be transformed for easier calculation to the form

$$V = \frac{7.75 \times 10^9}{P^2}$$

These results are in good agreement with those obtained by Carre and Laurent (9) in 1963. Their data, where the viscosities were obtained on an equiviscous shear rate for each penetration, have been recalculated by using viscosity as the dependent variable. Their equation, relating viscosity to penetration for penetrations above a value of 6.0, than becomes

$$\log V = 10.266 - 2.198 \log P$$

or

$$V = \frac{1.85 \times 10^{10}}{P^{2.198}}$$

This line lies well within the confidence bands shown in Figure 3. According to Carre and Laurent, this same relationship between viscosity and penetration holds at other temperatures reasonably close to 77 F.

The relationship between penetration at 77 F and viscosity at 275 F for the Ontario asphalt cements is shown in Figure 4. The lines of constant PI superimposed on the chart are again taken from Lefebvre (8). The current department specification limits for penetration and viscosity are shown also in this figure as shaded areas. The tight grouping of the plots for each grade of asphalt cement shows that the 2-point consistency specification has succeeded in its purpose of producing a reasonably regular quality for each grade of cement.

The current specifications issued by the department are producing the desired results. If the penetration at 77 F specification were to be superseded by a viscosity specification at, say, 140 F, then the new specifications would have to produce similar, or better, products. Some doubt has been expressed about the choice of 140 F as a suitable temperature at which to specify a viscosity range. It has been shown that a break occurs in the viscosity-temperature curve at, or just below, 140 F where waxy or blown asphalts are concerned (3, 4, 8). Some typical asphalt cements currently being supplied in Ontario are shown in Figure 5, in which pertinent data are plotted on a chart developed by Heukelom (3). The points used to plot these curves are penetration at 77 F, ring-and-ball softening point, and viscosities at 140 F and 275 F. All 3 types of asphalts described by Huekelom (3), S, B, and W types, are illustrated and are in regular use in Ontario. It can be seen from these figures that a transition is occurring within some asphalts at or below 140 F, causing the break in the curve. Heukelom (3) attributes it to the manner in which the waxes solidify and melt.

It is possible that the temperature of 140 F is above this transition range and will give an indication of how the asphalt will behave under the effects of traffic, as described by Krom and Dormon (10) and Heukelom (3). In view of the breaks that occur in the viscosity-temperature curves for certain asphalts, however, as shown in Figure 5, viscosity data at 140 F are not necessarily an indicator of the low-temperature performance of the asphalt cement. In the colder, northern regions of the United States and in all of Canada, good low-temperature performance is an important requirement of asphalt cements. Asphalts that become brittle at ambient winter temperatures tend to crack (11, 12) and lead to a more rapid deterioration of the pavement. At the present, the only tests of consistency at low temperatures, which are easily available, are the Fraass breaking point (which very few North American laboratories perform), the viscosity test with special apparatus for use at lower temperatures, and the penetration test. The most usual test made is the penetration test at 39.2 F with a 200 g load for 1 min. The results from this test unfortunately cannot be correlated with penetration results at 77 F because the time and the loading are different. Hence, they cannot help define the viscosity-temperature curve at low temperatures. Thus, at present, the majority of users of asphalt cements rely on the penetration at 77 F (or a combination of this with the penetration at 39.2 F) to give an indication of the low-temperature performance of the product.

At the Ontario Department of Highways, a new concept for determining low-temperature behavior of asphalt concrete (known as the critical temperature, T_C) is being investigated. This is defined as the temperature at which the asphalt cement can no longer flow fast enough to relieve the strains built up in the (restrained) asphalt concrete as it attempts to contract because of decreasing temperature. At this point, strains build up within the asphalt concrete; and if the temperature drops sufficiently, a transverse crack in the pavement results. The method of determining this property is described briefly in Appendix A.

The possibility of using the stiffness modulus to predict at what temperature a pavement will crack is also being investigated. By using this technique in reverse, an ap-

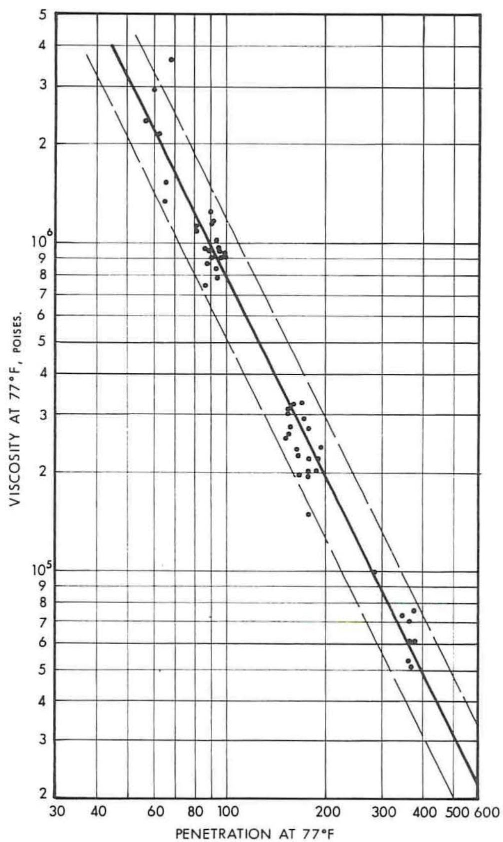


Figure 3. Viscosity at 77 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

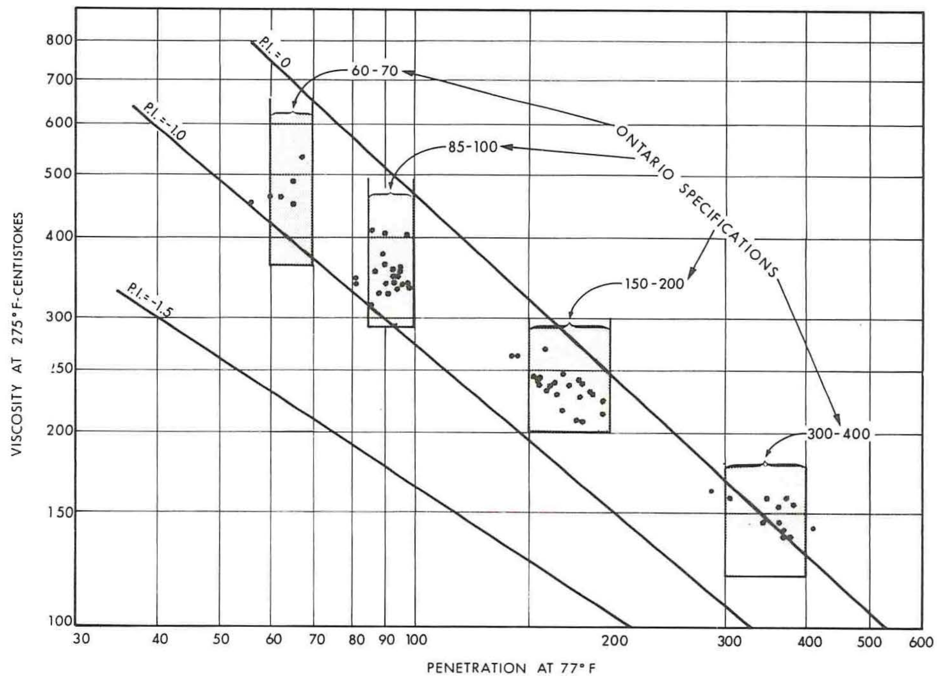


Figure 4. Viscosity at 275 F versus penetration at 77 F for Ontario asphalt cements used in 1969 and 1970.

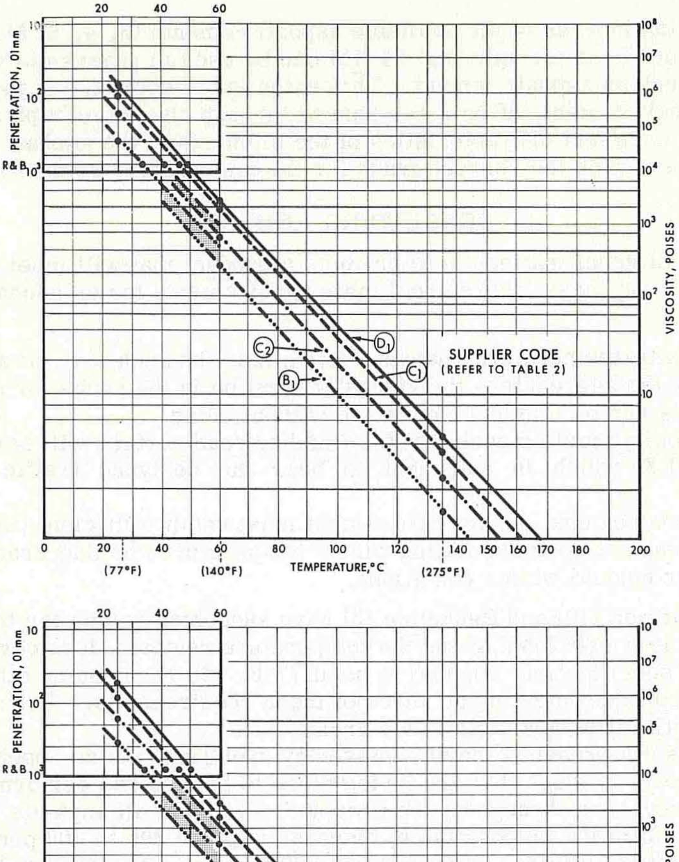


Figure 5. Temperature consistency relationships in Ontario asphalt cements.

propriate grade of asphalt cement can be selected that should yield a pavement with minimal susceptibility to cracking under a given temperature regime. This experimental design technique is described in detail in Appendix B. Briefly, the method is as follows:

It can be deduced from the report of Young et al. (12) that a pavement should still be crack-free when the stiffness modulus of the asphalt cement has reached 20,000 psi. By using this as a "safe" figure and a loading time of 10,000 secs and knowing the cor-

rected penetration indexes of the available asphalt cements (3, 4, 8) McLeod's modified charts for stiffness modulus and PI (15) can be used in reverse to yield a penetration value for such an asphalt cement. This value is, of course, the penetration value of the aged asphalt cement, after it has passed through the hot-mix plant. A knowledge of the thin-film oven test characteristics of the bitumens of the asphalt cement will then make it possible to pick the correct grade for the temperature regime in question.

CONCLUDING REMARKS

The purpose of specifications is to promote a product that will meet the user's requirements. Among these, there are 3 main requirements for an asphalt cement. These are as follows:

1. Its viscosity-temperature characteristics must be such that, at a temperature sufficient to dry the aggregates, the viscosity must be in the range for good mixing and such that the mix can be laid and compacted without delay.
2. The viscosity must be such that the finished road surface will have a stiffness modulus at 140 F, which is sufficient to bear the designed traffic load without deformation.
3. In northern regions, the asphalt cement must retain sufficient flow properties to relieve the strains set up under falling winter temperatures so that cracking will be minimized under normal winter conditions.

Krom and Dormon (10) and Heukelom (3) have suggested values for these 3 ranges that depend on the traffic loading and the temperature regime. It is obvious that a single consistency specification, whether it be at 77 F, 140 F, or some other temperature, cannot ensure a product meeting all three of these requirements. The range of temperature susceptibilities available is too great.

The department's present 2-point consistency specifications do appear to be limiting the asphalt cements to those that are giving close to the desired performance under the temperatures prevailing throughout the province. If higher PI asphalts were available (above 0.0), then it might be possible to dispense with the 300 to 400 penetration grade. In the current state of affairs, uniformity of construction techniques is being achieved by the use of a viscosity specification at 275 F. It now remains to be seen how softer asphalts will perform in service and whether the transverse cracking of the pavements to the northern sections of the province can be reduced.

REFERENCES

1. Welborn, J. F., and Halstead, W. J. Absolute Viscosity as a Specification Control for Bituminous Binders. AASHO 117th Meeting, Denver, Oct. 1961.
2. Hawthorne, H. R. Grading Asphalts by Viscosity. Proc. Canadian Technical Asphalt Assn., Vol. 10, 1965, p. 5.
3. Heukelom, W. A Bitumen Test Data Chart for Showing the Effect of Temperature on the Mechanical Behaviour of Asphaltic Bitumens. Jour. Inst. Pet., Vol. 55, 1969, p. 403.
4. Kopvillem, O., and Heukelom, W. The Effect of Temperature on the Mechanical Behaviour of Some Canadian Asphalts as Shown by a Test Data Chart. Proc. Canadian Technical Asphalt Assn., Vol. 14, 1969, p. 262.
5. The Asphalt Handbook, 1965 Edition. The Asphalt Institute, Manual Series 4, p. 57.
6. McLeod, N. W. Critical Appraisal of Proposal to Grade Paving Asphalts by Viscosity at 140 Degrees F. ASTM, STP 424, 1967, pp. 47-82.
7. Zdeb, M. S. Asphalt Cement Viscosity and Penetration. Engineering Research and Development Bureau, New York State Department of Transportation, Research Rept. 69-15, March 1970.
8. Lefebvre, J. A. A Modified Penetration Index for Canadian Asphalts. AAPT Proc., Vol. 39, 1970.
9. Carre, G., and Laurent, D. The Relationship Between the Penetration and Viscosity of Bitumens. Association Francais des Techniciens du Petrole, Bull. 157, Jan. 31, 1963; Shell Bitumen Reprint 16.

10. Krom, C. J., and Dormon, G. M. Performance Requirements for Road Bitumens and Their Expression in Specifications. Proc. 6th World Petroleum Congress, 1963; Shell Bitumen Reprint 15.
11. Haas, R. C. G., et al. Low Temperature Pavement Cracking in Canada; the Problem and Its Treatment. Proc. Canadian Good Roads Assn., Montreal, 1970.
12. Young, F. D., et al. Ste. Anne Test Road, A Field Study of Transverse Crack Development in Asphalt Pavements. Proc. Canadian Technical Asphalt Assn., Vol. 44, 1969, p. 50.
13. Van der Poel, C. A General System Describing the Visco-Elastic Properties of Bitumens and Its Relation to Routine Test Data. Jour. Applied Chemistry, May 1954.
14. Pfeiffer, J. P., and Van Doormal, P. M. The Rheological Properties of Asphaltic Bitumen. Jour. Inst. Petrol, Technologists, Vol. 22, 1936, p. 414.
15. McLeod, N. W. Transverse Pavement Cracking Related to Hardness of the Asphalt Cement. Proc. Canadian Technical Asphalt Assn., Vol. 13, 1968, p. 5.
16. Thomas, M. K. Climatological Atlas of Canada. National Research Council, Ottawa, NRC 3151, DBR 41, Dec. 1953.

Discussion

J. YORK WELBORN, Federal Highway Administration—The authors point out that the 1970 Ontario asphalt-cement specification has nearly eliminated the use of all asphalt cements having a PI of less than -1.0 by using appropriate limits for kinematic viscosity at 275 F. A comparison of the restrictions imposed on penetration-grade asphalts by high-temperature viscosity to similar restrictions that might be used in the AASHO Specifications for Viscosity Graded Asphalts is of interest.

Figure 2 of the author's report shows the relationship between viscosity at 140 F and penetration at 77 F and provides a basis for such a comparison. An asphalt cement of 2.5 grade is shown to compare with the soft asphalt of 300 to 400 penetration included in the Ontario specification. By using the AASHO viscosity limits at 140 F, the penetration ranges for the Ontario asphalts on a viscosity-graded basis would be as given in Table 3.

TABLE 3

PENETRATION RANGES FOR ONTARIO ASPHALTS

Viscosity Grade	Viscosity at 140 F	Penetration at 77 F: Ontario Asphalts	Penetration at 77 F: AASHO Specification
AC-2.5	200 to 300	220 to 420	—
AC-5	400 to 600	140 to 280	120+
AC-10	800 to 1200	90 to 180	70+
AC-20	1600 to 2400	60 to 120	40+
AC-40	3200 to 4800	40 to 80	20+

These data support our contention that higher minimum penetration requirements may be justified in the AASHO specification to reduce the thermal or transverse cracking problem. The higher minimum limits together with the addition of a lower viscosity grade, such as AC-2.5, should provide a more suitable specification for selecting and controlling asphalt cements for use in low-temperature environmental areas.

H. J. FROMM AND W. A. PHANG, Closure—As Welborn points out, the penetration requirements in the AASHO specification are not high enough for the corresponding gradings at 140 F if a higher PI asphalt with good low-temperature performance is desired. The AASHO specification permits asphalts with PI's down to -1.5. We believe some degree of PI control is necessary if we are to obtain good low-temperature performance and also a minimum of difficulties during the actual construction of the road.

Appendix A

Coefficient of Expansion

The Coefficient of Expansion of the asphalt concrete mix is needed to determine the amount of strain deformation built up in a restrained road slab as temperatures fall below the Critical Temperature, (T_C). Shrinkage in the material at temperatures above the T_C is accommodated by flow of the asphalt binder.

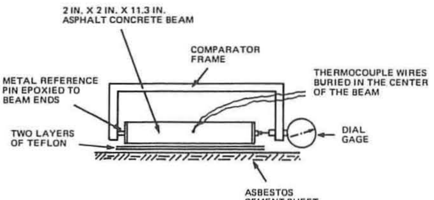


Figure A1, Apparatus for Determining the Coefficient of Expansion of Asphalt Concrete Mixes

The apparatus illustrated in Figure A1 is used for finding the coefficient of expansion of asphalt concrete mixes within a temperature range of −20 degrees F. to +20 degrees F. The asphalt beam is cooled to about −20 degrees F., then placed in the apparatus at room temperature, and the changes in length of the beam at increments of temperature change are recorded and used to determine the coefficient of expansion. Two teflon layers are needed to provide a base with a low restraint value; base restraint causes irregular motion and smaller movements.

Measuring Creep Deformation

The apparatus illustrated in Figure A2 is used for measuring the creep deformation of asphalt concrete mixes at low temperatures (−10 degrees F., to +40 degrees F.), under a constant small tensile stress. The load/unload cycle is monitored for deformation over the 30 minute load cycle (20 minute rest) and measurements are averaged over the second and third cycles, provided these are consistent. (Temperature variations of more than 1 degree F. over the test period result in inconsistent tests and further cycles must be run.) A typical creep deformation curve is illustrated in Figure A3, and the test is repeated at different temperatures. The viscous part of the creep curve is caused by the flow in the asphalt binder, and it is this quality of the mix which is of interest. If the flow which occurs in a unit length of mix over a time period of one hour is considered, this can be compared against the amount of shrinkage induced by the temperature change of the mix during the same one hour period if it had not been restrained. At temperatures higher than T_C it will be found that this viscous flow exceeds the induced shrinkage due to temperature change. As illustrated in Figure A4, however, at temperatures below T_C, the restrained temperature shrinkage cannot be accommodated by flow in the asphalt binder, and, instead, tensile strains must be developed in the restrained material. Of course, if temperatures fall low enough below this critical temperature, the induced tensile strains can cause cracks to form.

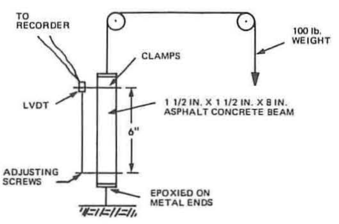


Figure A2, Apparatus for Measuring Creep Deformation Under Constant Tensile Stress

An examination of hourly temperature records from various locations in the Province indicate that the ambient temperature drop during a one hour period does not exceed 10 degrees F. at temperatures below 0 degrees F. The critical temperatures are therefore determined for the amount of induced shrinkage which would occur over a 10 degree F. temperature drop, i.e., for an hourly deformation of ten times the coefficient of expansion.

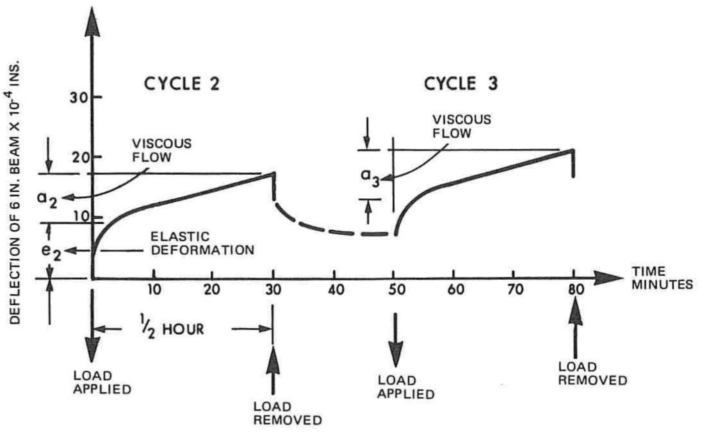


Figure A3, Example of a Creep Test Result

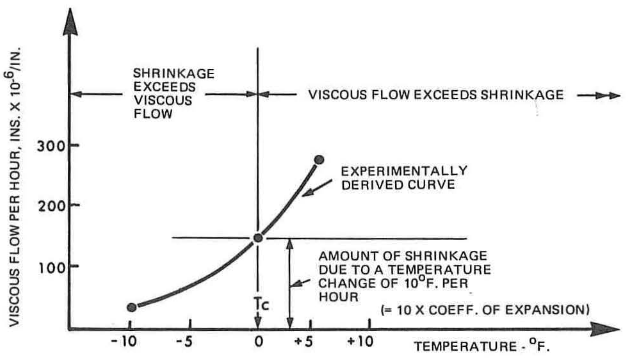


Figure A4, Example of a Critical Temperature Determination

Appendix B

The stiffness modulus of an asphalt binder is a function of its temperature and depends on the loading time [13], the penetration and the P.I. [14]. Figure B1 shows the stiffness modulus at various temperatures of the asphalt binders used at the Ste. Anne Test Road [12]. The difference in stiffness between the 150/200 pen. asphalts of high and low viscosities (temperature susceptibilities) can be seen to increase as the temperature decreases.

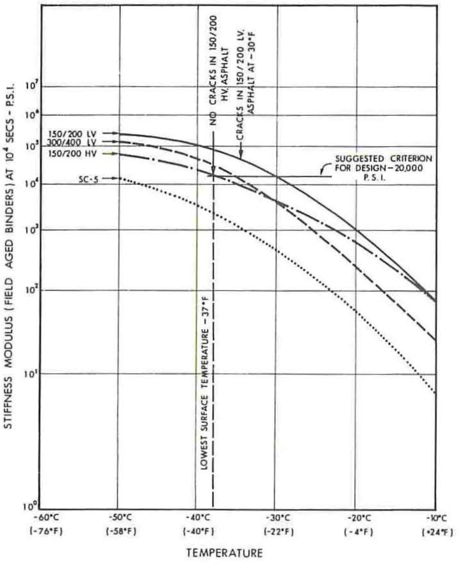


Figure B1, Suggested Stiffness Modulus Criterion (After Young et al - Ste. Anne Test Road, CTAA 1969)

Crack initiation in the 150/200 pen. LV asphalt occurred at a temperature of −30 degrees F. or at a stiffness modulus of about 40,000 psi. The 150/200 pen. HV asphalt did not crack even at a temperature of −37 degrees F. at which point the stiffness modulus was 20,000 psi.

It therefore appears possible to make an initial assumption that crack initiation in all binders will not occur at a stiffness modulus of less than 20,000 psi; this criterion can later be amended for other asphalt grades, temperature susceptibility and temperature environments as further observations prove the necessity.

Figures B2 and B3 are the modified nomographs suggested by McLeod [15] which can be used to characterise the rheological behaviour of asphalt binders. Plotted on Figure B3 is the low temperature failure criterion of a stiffness modulus of 20,000 psi or 1,400 Kg/cm². From this figure, if an asphalt with a P.I. of −1.5 is selected at a loading time of 10,000 seconds, the criterion gives a temperature of 72 degrees C. below the base temperature. This temperature is made up of three parts,

(a) the temperature difference in degrees C. between the base temperature and the temperature employed in the penetration test,

(b) The temperature (degrees C.) at which the penetration test is performed and,

(c) the temperature below 0 degrees C. at which the failure criterion applies.

As an example, if a design temperature of −30 degrees F. (−34 degrees C.) is assumed, and the penetration test is carried out at 25 degrees C., then the temperature difference between the base temperature and the temperature of the penetration test is 72 − (25 + 30) = 17 degrees C. Entering this temperature difference in Figure B2 and with the P.I. of −1.5, gives a penetration value of 110. Similarly, other penetration values for other design temperatures and P.I. values can be obtained, and these are shown plotted in Figure B4.

The stiffness modulus criterion of 20,000 psi was for the field-aged binder, so it is necessary to examine the specifications after the thin film oven test, which simulates the hardening of the binder during the mixing and laying process. The three shaded bands on Figure B4 represent the minimum conditions resulting from the D.H.O. specifications and it is now apparent from the diagram that satisfactory performance can be obtained at a particular design temperature, from a wide range of asphalt penetration grades, dependent on the P.I. value of the asphalt. It is also apparent that the degree of hardening which occurs during the mixing and placing is an extremely important factor which could largely influence the subsequent performance.

Figure B5 shows winter design temperatures for Canada compiled on a one percent basis by the National Research Council and the Department of Transport [16]. Using this map to determine the required design temperature, it is then possible to use Figure B4 to select the field-aged penetration of the asphalt cement and the P.I. Knowing the minimum specified percentage of retained pen., the penetration grade can be selected, and from the P.I. value, the minimum viscosity at 275 degrees F. can be determined from Figure 4.An asphalt cement which

conforms with these requirements can then be selected from those available.

From Figure B4, it can be seen that crack initiation in the asphalts complying with the Ontario specifications would not occur at temperatures above the following limits:

300-400 pen. asphalt −33 degrees F.

150-200 pen. asphalt −24 degrees F.

85-100 pen. asphalt −12 degrees F.

From these limits, it is possible to designate construction areas in which specific asphalt cement grades can safely be used.

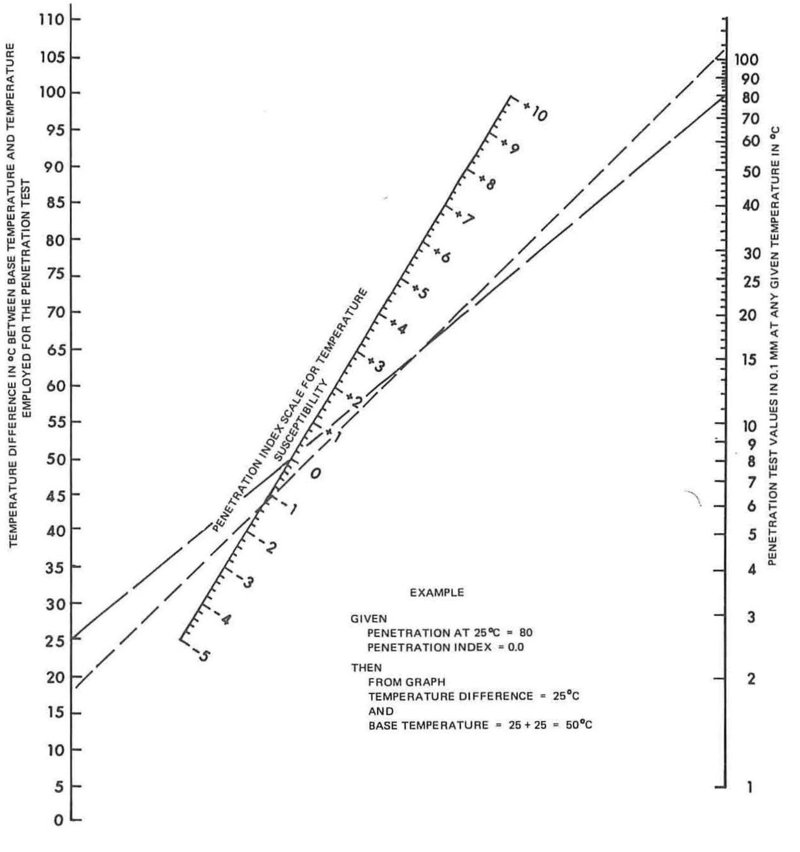


Figure B2, Suggested Modification of Heukelom's Version of Pfeiffer's and Van Doormal's Nomograph for Relationship Between Penetration, Penetration Index and Base Temperature (After McLeod)

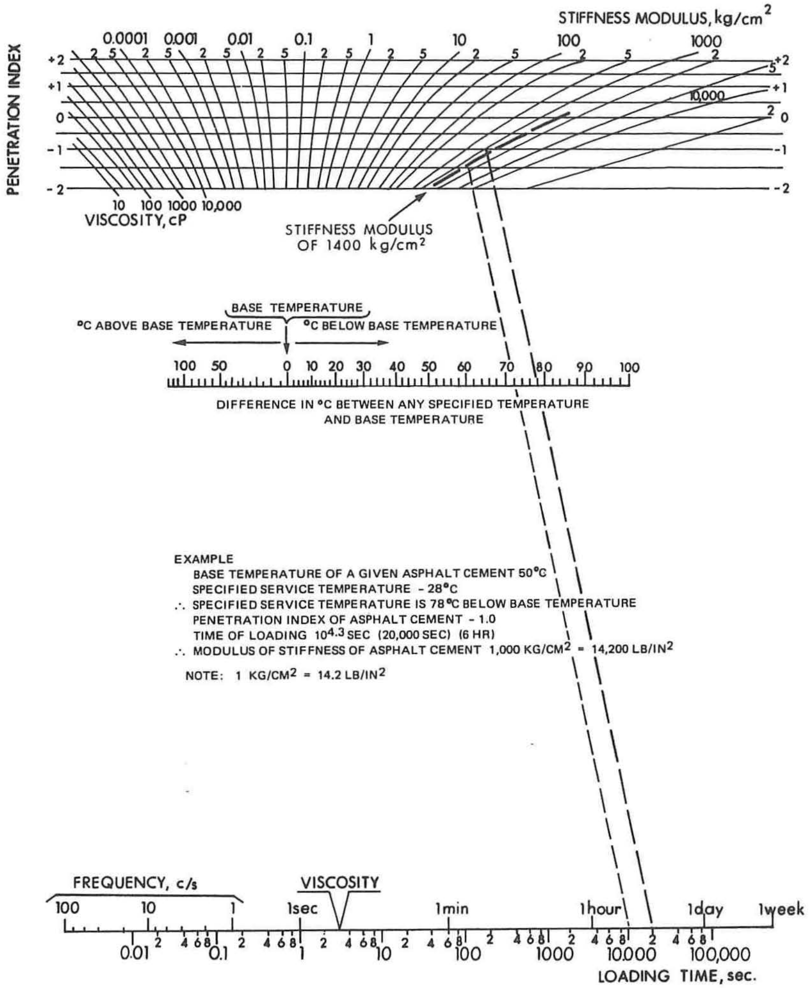
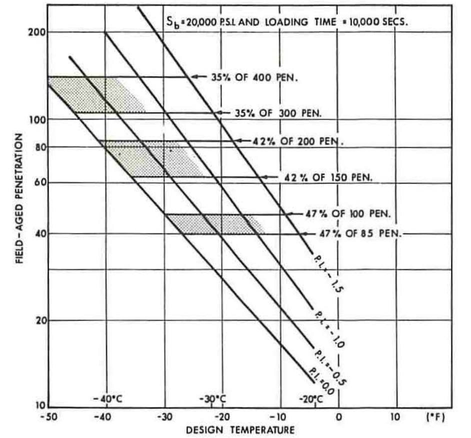


Figure B3, Suggested Modification of Heukelom's and Klomp's Version of Van der Poel's Nomograph for Determining Modulus of Stiffness of Asphalt Cements (After McLeod)



Note: Percentages are for Retained Penetration after Thin Film Oven Test - D.H.O. Specifications

Figure B4, Selecting Asphalt Cement from Design Temperature (1%)

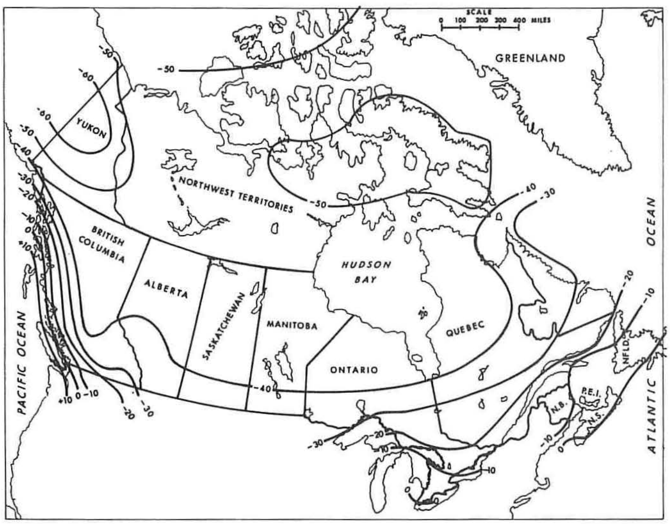


Figure B5, Winter Design Temperature 1% Basis (°F.)

PAVING ASPHALT PROPERTIES

William H. Gotolski, Richard W. Smith, and James M. Roberts,
Pennsylvania State University

This investigation of changes in asphalt contained in asphaltic mixes was undertaken to gain an understanding of the factors affecting the durability of asphalt pavements. Pavements were constructed to determine penetration-absolute viscosity relationships for the different asphalts used. Six different asphalts were used, varying in penetration and absolute viscosity. Three pavements were constructed by using the same 6 asphalts, but each was constructed with different aggregate types. Investigations were confined to the wearing course. The test pavements were asphaltic concrete overlays on portland cement concrete. Field data were accumulated during construction and periodically after construction. Penetration, absolute viscosity, and asphaltene determinations were made. Results from these projects indicate that a low-viscosity asphalt (90 to 100 penetration and 900 ± 200 poise viscosity) is performing as well as or better than the other asphalts. This is based on a rating system, devised by the authors, relating physical and chemical changes with air void changes with time.

•AN ASPHALT pavement is a system of layered viscoelastic solids. The layers that contain asphalt form 3-phase systems that consist of aggregates of various shapes and sizes, an asphalt film that binds the stones together, and air voids. As asphalt is but a minor component of a pavement (about 6 percent by weight), its contribution to the durability of the pavement is difficult to assess (1). Although much care has been exercised in the construction of asphalt pavements in the past, experience with some bituminous roadways in Pennsylvania indicates a deterioration of the roadways as manifested by cracking, raveling, bleeding, and abrasion losses. These deteriorating properties have been known to occur in asphalt pavements irrespective of the age of the pavement. It is thought that deterioration occurs because of the hardening or increasing brittleness that generally accompanies the in-service life of an asphalt pavement (2, 3, 4, 5). Hardening of an asphalt pavement is confined to the asphalt. Any investigation of the hardening of an asphalt mix should concentrate, therefore, on the changing properties of the asphalt. Under the sponsorship and with the cooperation of the Federal Highway Administration and the Pennsylvania Department of Transportation, the Civil Engineering Laboratories of the Pennsylvania State University have undertaken an investigation of the physical and chemical properties of asphaltic concrete material of in-service projects.

OBJECTIVES

The principal aim of this investigation is to study the physical and chemical changes of the asphalt and asphaltic concrete mixture with passage of time. In particular, the asphalt in these pavements will be tested for the purpose of arriving at relationships of penetration to absolute viscosity. Three pavements were constructed in order to determine whether penetration specifications for asphalt should be complemented by absolute viscosity specifications. The penetration-absolute viscosity relationship of the various asphalts used are being investigated for its influence on pavement durability.

Sponsored by Committee on Characteristics of Bituminous Materials and presented at the 50th Annual Meeting.

TEST PROJECTS

Each test pavement was constructed by using 6 different asphalt cements. The same 6 asphalts were used on each pavement. Within each test pavement, the same aggregate source and aggregate gradation was used. Different aggregate sources and aggregate gradations were used among test pavements, as follows:

County	Route	Aggregate
Clinton	LR 219	ID-2 crushed limestone
McKean	LR 101	ID-2 sand and gravel mixture
Jefferson	LR 338	FJ-1 sand mixture

These gradations are given in Table 1. The Clinton County project is in the central portion of Pennsylvania on US-220; the Jefferson County project is in the west-central portion on US-119; and the McKean County project is in the north-central portion on US-6.

The initial consistency properties of the asphalts evaluated in this study are given in Table 2. Some were typical road materials used in Pennsylvania and others were specially prepared for use in the study. The specification values are given along with the values obtained from tests performed on samples obtained at the paving contractor's plant. Other initial data, including construction data and time data, have been presented by the researchers and are available in the literature (6).

TESTING PROCEDURES

The sampling and construction procedures were formulated for each project in advance of field construction of each roadway. A complete discussion of these procedures was reported in 1967 (7). The testing procedures for an asphalt cement adopted for this investigation included: penetration, ASTM Designation D 5-65, and absolute viscosity, ASTM Designation D2171-63T.

Past studies (8, 9, 10) indicate a relationship between chemical composition and asphalt durability. Chemical analyses were performed by using a procedure described in earlier literature (11). The work of Rostler and White (8) defines asphalts as consisting of 5 basic constituents: asphaltenes, nitrogen bases, first acidaffins, second acidaffins, and saturated hydrocarbons. By precipitation, this method isolates these 5 constituents, the values of which are determined by differential weighing and then reported as percentages of the total sample weight. The initial values of the chemical composition are given in Table 3.

Specific gravity determinations, using Pennsylvania Department of Transportation specifications, were made on the mix samples by the department's laboratory to ascertain degrees of compaction at construction and during service life.

Asphalt cement samples were obtained from mix and field core specimens by the Immerex (immersion-reflux) method of extraction and the Abson method of recovery, ASTM Designation D1856-65. Benzene was used as the solvent to minimize any chemical reaction between solvent and asphalt during the contact time of the recovery process.

TABLE 1

TYPICAL GRADATIONS USED ON EACH PROJECT

Sieve	Percent Passing		
	Route LR 219	Route LR 101	Route LR 338
½ in.	100.0	100.0	100.0
⅜ in.	96.2	91.5	100.0
No. 4	65.6	67.7	98.0
No. 8	46.9	45.0	75.0
No. 16	34.3	32.9	53.0
No. 30	24.7	24.1	43.0
No. 50	13.6	12.3	32.0
No. 100	7.6	7.1	14.0
No. 200	5.3	3.6	6.0

RESULTS

The specific test values of penetration, absolute viscosity, and percentage of asphaltenes for each asphalt used on each test pavement have been presented elsewhere (6, 7, 12, 13). In order to look at asphalt hardening relative to all other asphalts, the authors believe a clearer picture of what has occurred is best accom-

TABLE 2

ASPHALT CEMENT SPECIFICATIONS

Asphalt	Route	Penetration at 77 F[a]	Viscosity at 140 F[b]	Reported Penetration at 77 F[a]	Reported Viscosity at 140 F[b]
I	LR 219	50 to 75	1,500 ± 200	59	1,732
	LR 101			59	1,895
	LR 338			67	1,782
II	LR 219	90 to 100	1,500 ± 200	89	1,548
	LR 101			91	1,472
	LR 338			86	1,630
III	LR 219	140 to 160	1,500 ± 200	146	1,440
	LR 101			130	1,701
	LR 338			136	1,526
IV	LR 219	90 to 100	900 ± 200	110	949
	LR 101			84	1,090
	LR 338			87	1,047
V	LR 219	90 to 100	3,000 ± 200	94	2,136
	LR 101			85	2,970
	LR 338			84	3,159
VI	LR 219	70 to 85	3,000 ± 200	77	2,951
	LR 101			74	3,124
	LR 338			74	3,092

[a]1/10 mm at 100 gm, 5 sec. [b]Poises at 30 cm Hg vacuum.

plished through graphical presentations. Consequently, graphs are used in place of tabulated data wherever possible. All figures involving changes in penetration with time, viscosity with time, and so on are drawn by using the first sample that initiated an annual pattern of sampling on the particular test pavement. In the use of such samples, only the asphalt hardening that occurred from construction on is reflected in the figures. The penetration, viscosity, and asphaltene content of these samples were used as the base (authors now call these the original values) for determining percentage retained penetration, percentage of original viscosity, and percentage of original asphaltenes.

TABLE 3

ASPHALT COMPOSITIONS BEFORE MIXING

Asphalt	Route	Component[a] (percent)					Rostler Coefficient
		A	N	A_1	A_2	SH	
I	LR 219	20.9	22.5	16.0	29.0	11.6	0.95
	LR 101	17.2	23.1	15.3	28.0	16.4	0.87
	LR 338	19.0	23.1	16.8	29.5	11.7	0.97
II	LR 219	19.2	23.2	13.3	30.5	13.8	0.82
	LR 101	20.8	22.8	15.2	26.6	14.6	0.92
	LR 338	22.3	20.9	16.0	28.6	12.1	0.91
III	LR 219	26.8	15.9	14.7	30.9	11.8	0.72
	LR 101	29.6	14.5	16.8	25.2	14.0	0.80
	LR 338	27.8	19.0	17.4	27.3	9.4	0.99
IV	LR 219	19.5	18.9	13.7	33.7	14.3	0.68
	LR 101	15.2	25.6	16.8	28.4	14.0	1.00
	LR 338	16.8	23.0	15.6	31.5	13.1	0.87
V	LR 219	28.2	20.6	18.0	24.3	8.7	1.17
	LR 101	29.6	15.0	16.6	25.4	13.4	0.81
	LR 338	29.5	17.0	17.8	25.8	9.9	0.98
VI	LR 219	28.2	22.6	17.7	23.5	8.0	1.25
	LR 101	29.6	20.6	18.8	19.4	11.6	1.27
	LR 338	28.2	22.9	21.5	21.0	6.5	1.61

[a]A = asphaltenes; N = nitrogen bases; A_1 = first acidaffins; A_2 = second acidaffins; and SH = saturated hydrocarbons.

The percentages of air voids that existed for each test pavement were (based on the average of the 6 asphalts) as follows: LR 219, 10.4; LR 101, 7.8; and LR 338, 12.1. Comparisons of these values show that LR 101, as a whole, was constructed at a lower level of air voids than LR 219 and LR 338; and LR 219, as a whole, was constructed at a lower level of air voids than LR 338. Influence of air voids will be discussed more fully in later paragraphs.

Penetration

Figure 1 shows the penetration-time relationship for LR 219, LR 101, and LR 338. The relative positions of the asphalts in LR 219 show little change with passage of time.

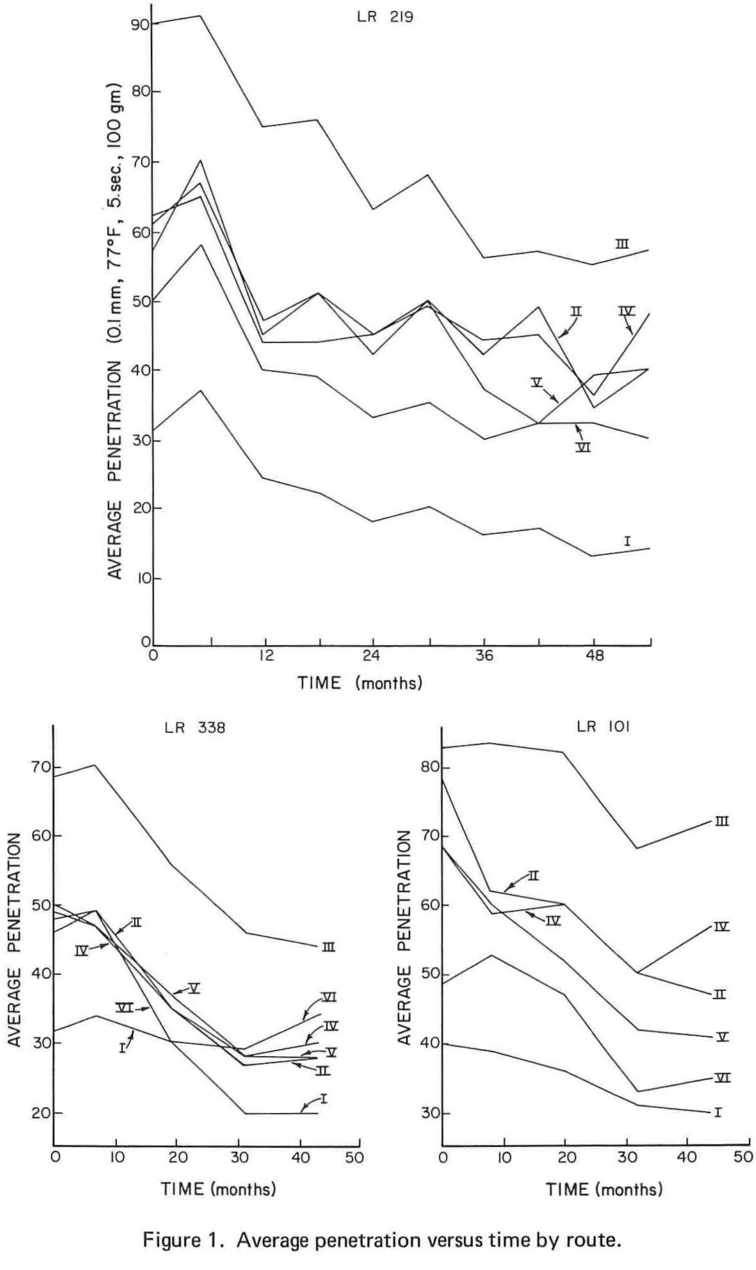


Figure 1. Average penetration versus time by route.

The penetration-time relationships for LR 101 and LR 338 do not exhibit the saw-toothed curves on a scale as grand as that of LR 219. The segments of the curves for LR 101 and LR 338 represent annual hardening whereas those for LR 219 represent biannual hardening.

Figure 2 shows the penetration-time relationships for the different asphalts. There are differences in levels of hardness of the asphalts among the pavements. It is not so

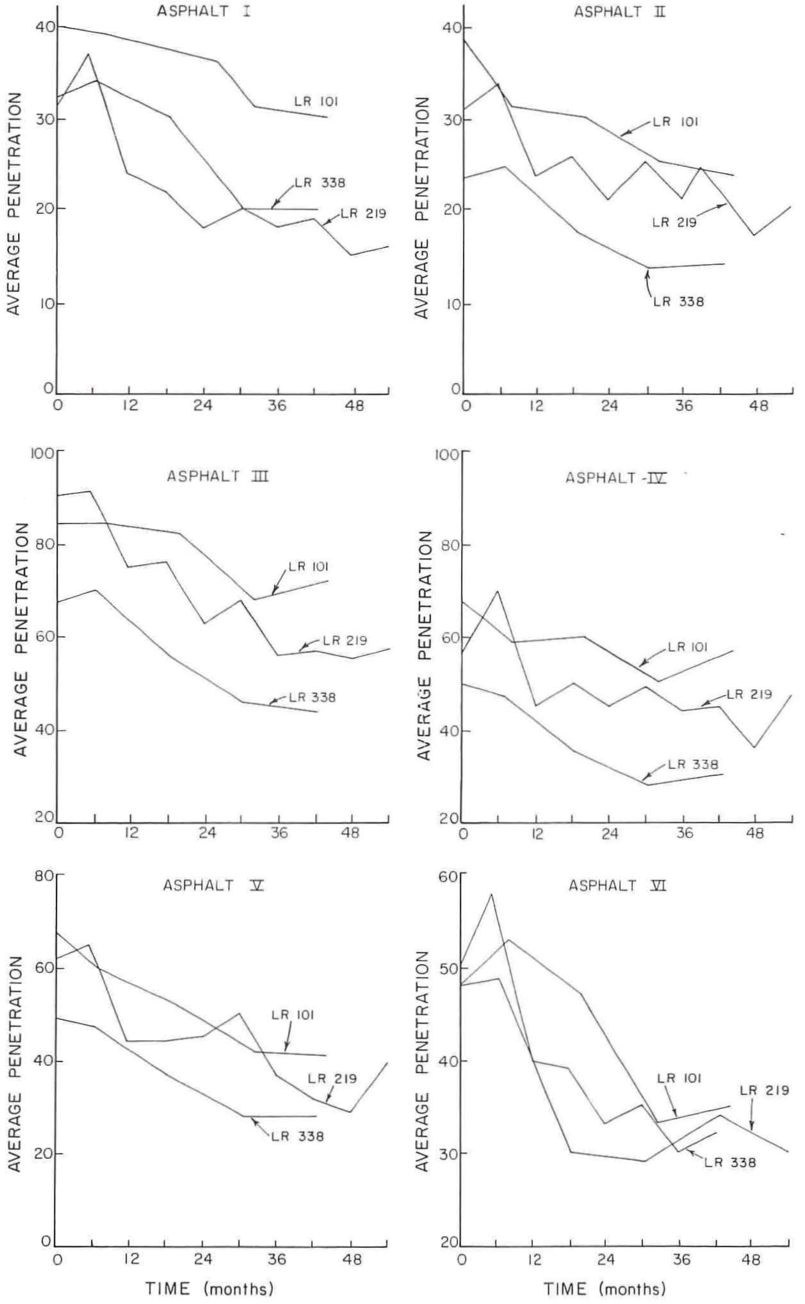


Figure 2. Average penetration versus time by asphalt.

readily observed whether there are differences in rates of hardening of the asphalts among pavements. Figure 3 is identical to Figure 2 (asphalt II) except for the manner in which penetration-time curves are drawn for LR 219. The dashed lines in Figure 3 show how the data for LR 219 are shown in Figures 1 and 2. The saw-toothed nature of the LR 219 curves in Figures 1 and 2 are believed to be explained in Figure 3 and is attributed to winter and summer environmental conditions. Additional discussion pertaining to this saw-tooth phenomenon is presented elsewhere (12). LR 219 has been sampled twice every year, and LR 101 and LR 338 have been sampled once a year. Therefore, data shown in Figure 3 for LR 219 were separated into 2 penetration-time curves: one based on spring-coring data and one based on fall-coring data. Each curve

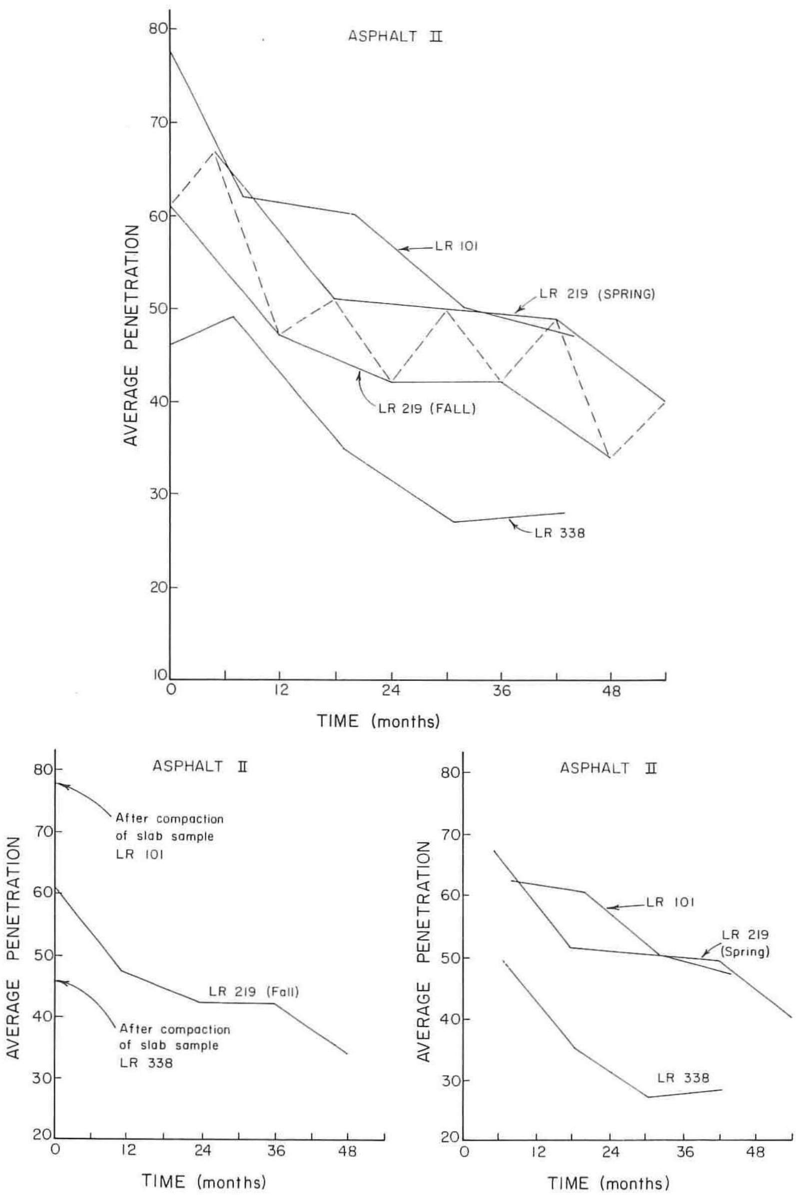


Figure 3. Average penetration versus time for asphalt II by coring time.

now represents annual sampling. It becomes apparent that consideration must be given to the time of the year that a test pavement is sampled. If, for example, LR 219 was sampled only in the fall, one would be led to believe that this pavement was hardening at some rate midway between LR 101 and LR 338. On the other hand, if LR 219 was sampled only in the spring, one would be led to believe that this pavement was hardening at some rate similar to LR 101.

Figure 3 also shows the data according to fall and spring sampling respectively. If a comparison of asphalt performance is to be made between the test pavements, it must be made from the spring sampling results. As a result, to put the 3 pavements on a direct comparison basis, the initial hardness of the pavement cannot be considered in the following analysis.

Figure 4 shows the percentage of retained (of original, as defined earlier) penetration values for the 4 years the pavements have been in existence. Asphalt performance may be compared within the pavements. Data for LR 219, fall coring, do not yield the same results as data for LR 219, spring coring. This is one of the most important findings of this investigation and was pointed out earlier (12). Asphalt IV has hardened to a lesser degree on the respective test pavements. Similarly, asphalt I for LR 219, asphalt VI for LR 101, and asphalt II for LR 338 have hardened to the greatest degree on their respective test pavements. When one asphalt shows a slower degree of hardening on one test pavement and a greater degree of hardening on another, one must

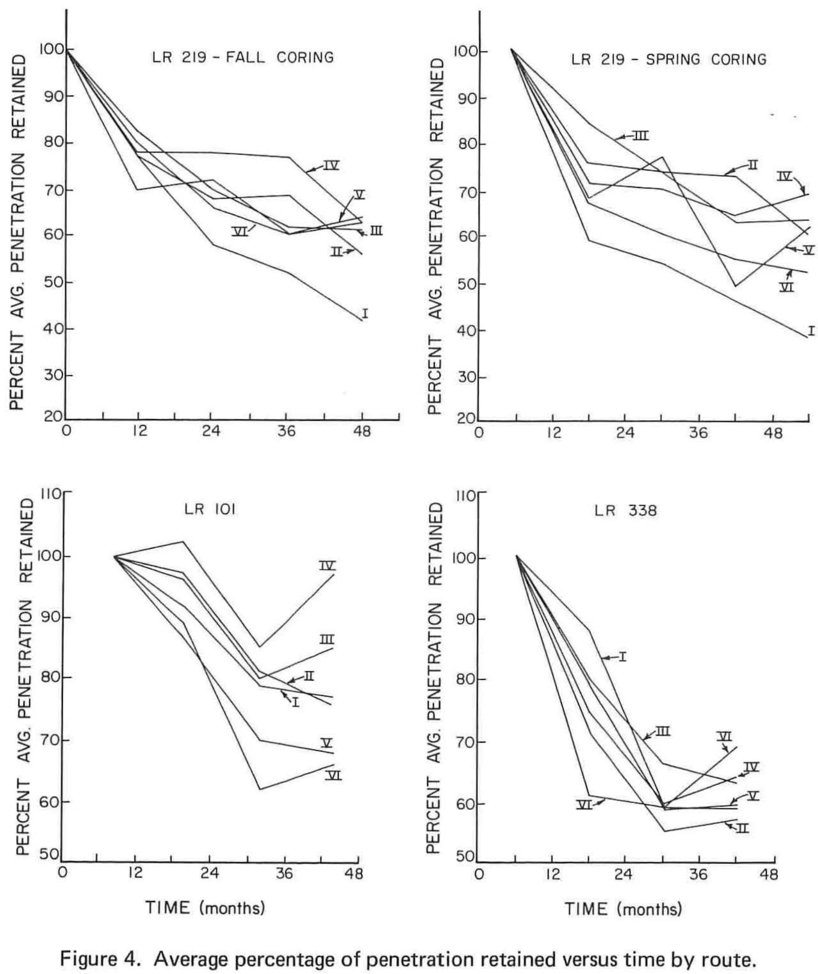


Figure 4. Average percentage of penetration retained versus time by route.

conclude that there must be one or more factors more important to asphalt hardening in a pavement than asphalt type.

Figure 5 shows more clearly the different manner in which the same asphalt is performing on the individual pavements. In 4 cases, the asphalts on LR 338 have hardened

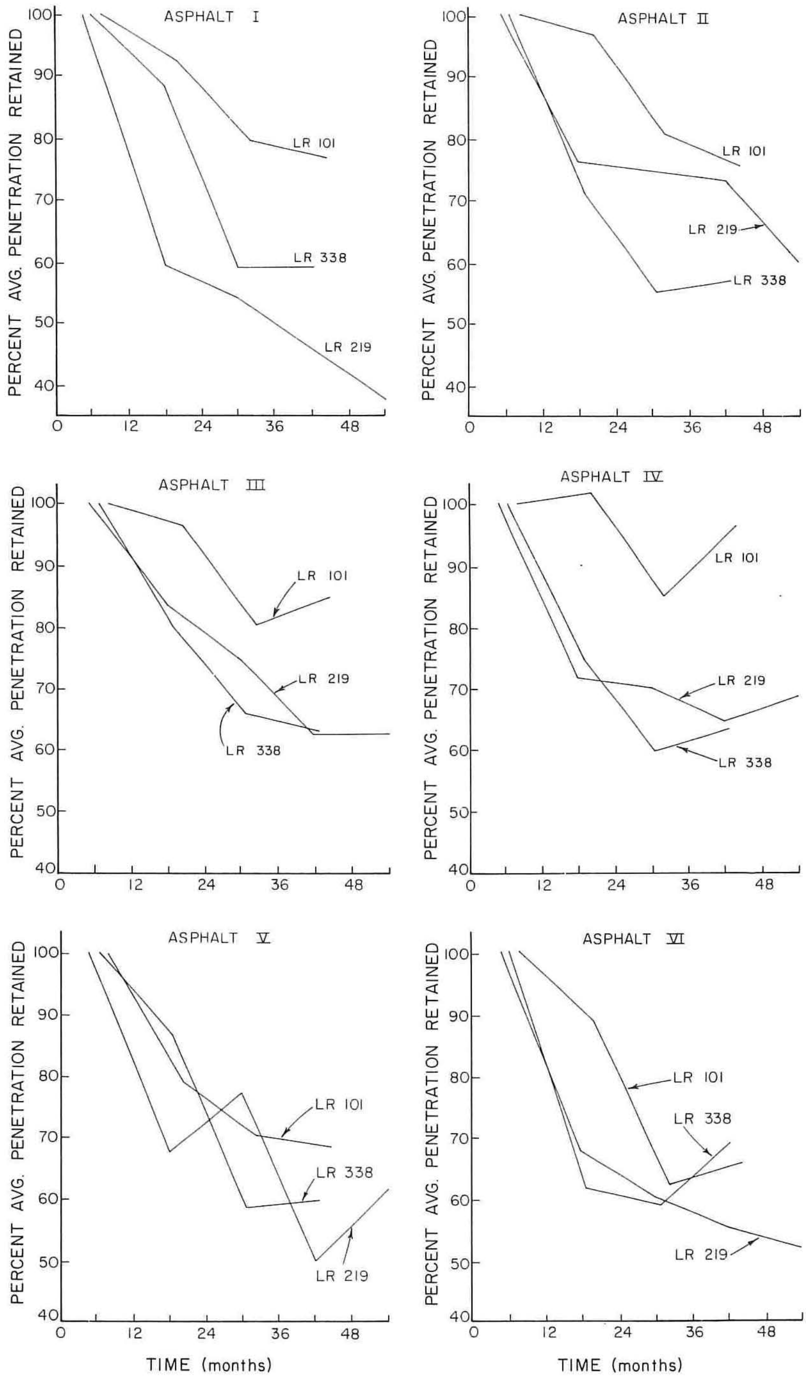


Figure 5. Average percentage of penetration retained versus time by asphalt.

to a greater extent in the same period of time than the asphalts on LR 219 and LR 101. Further, asphalts on LR 101 remain softer than those on the other 2 pavements. One obvious explanation for these differences is the differences in percentage of air voids among the pavements. As stated earlier, this subject will be discussed more fully in later paragraphs.

Absolute Viscosity

Figure 6 shows the absolute viscosity data for LR 219, LR 101, and LR 338. These curves and those in Figure 1 for the penetration results are presented in the same fashion. For observing asphalt hardening, it can be said that these viscosity-time relationships yield the same conclusions as those drawn for penetration-time relationships (7).

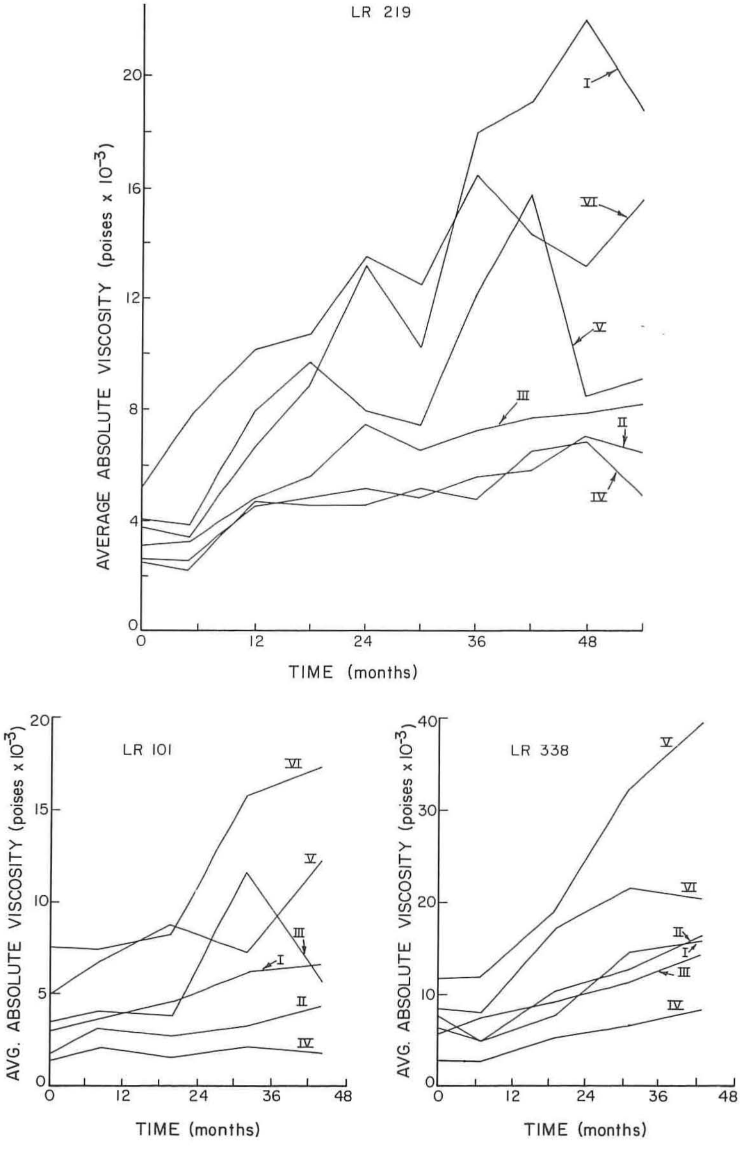


Figure 6. Average absolute viscosity versus time by route.

Data for LR 219 reveal the same saw-toothed trends as those shown on some of the previous penetration graphs. Figure 7 shows the percentage change of viscosity with time.

Chemical Composition

Figure 8 shows the continuing trends of asphaltene content with time. Asphalts I, II, and IV continue to show asphaltene contents lower than those of asphalts III, V, and VI. At the present time, it is still too early to determine what significance, if any, this may mean in terms of pavement durability. Figure 9 shows how the time of the pavement sampling can influence test results that may influence the durability comparison.

In the continuing studies of these 3 test pavements, it has been found that changes in the percentage of asphaltene fraction correlate with changes in penetration and absolute viscosity (7, 12). It has also been hypothesized (7, 12) that pavement variables such as air voids and permeability overshadow performance differences among asphalt cements. In essence, it may be summarized by the authors that a type A asphalt that differs in chemical composition from a type B asphalt should not be chosen over a type B asphalt but that both asphalts could be used in a highway pavement as long as air void specifications for the pavements were designed to compensate for the durability differences among asphalt cement types.

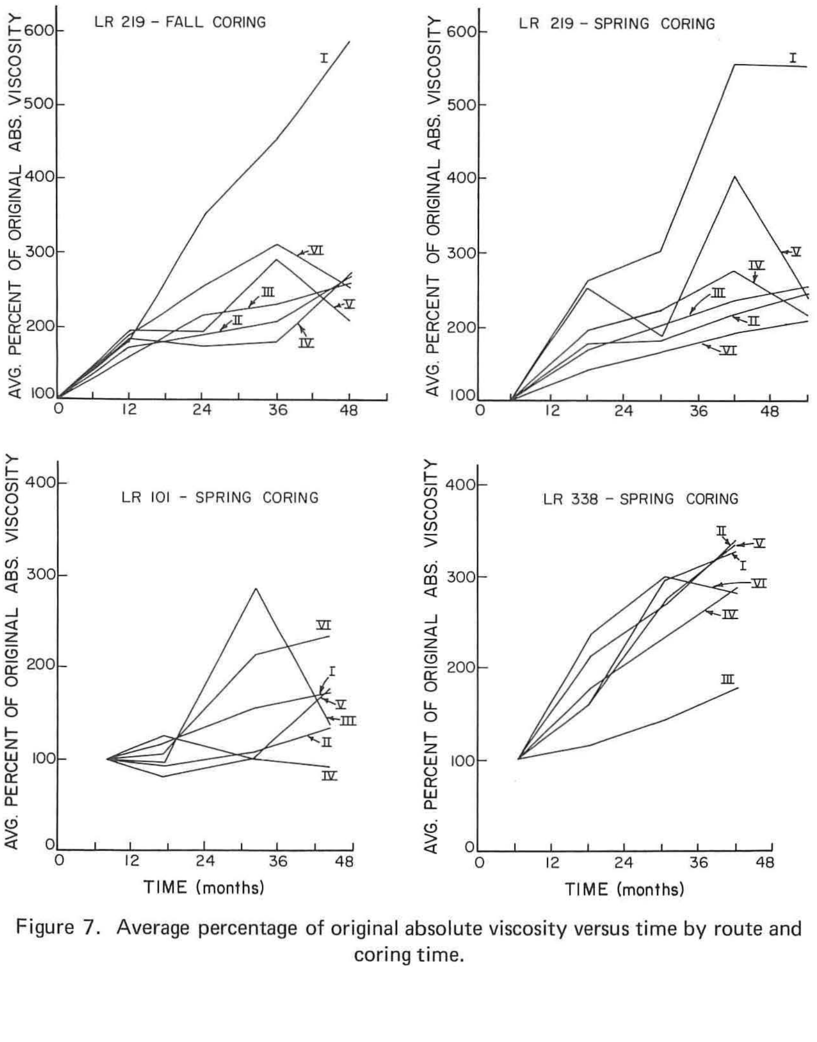


Figure 7. Average percentage of original absolute viscosity versus time by route and coring time.

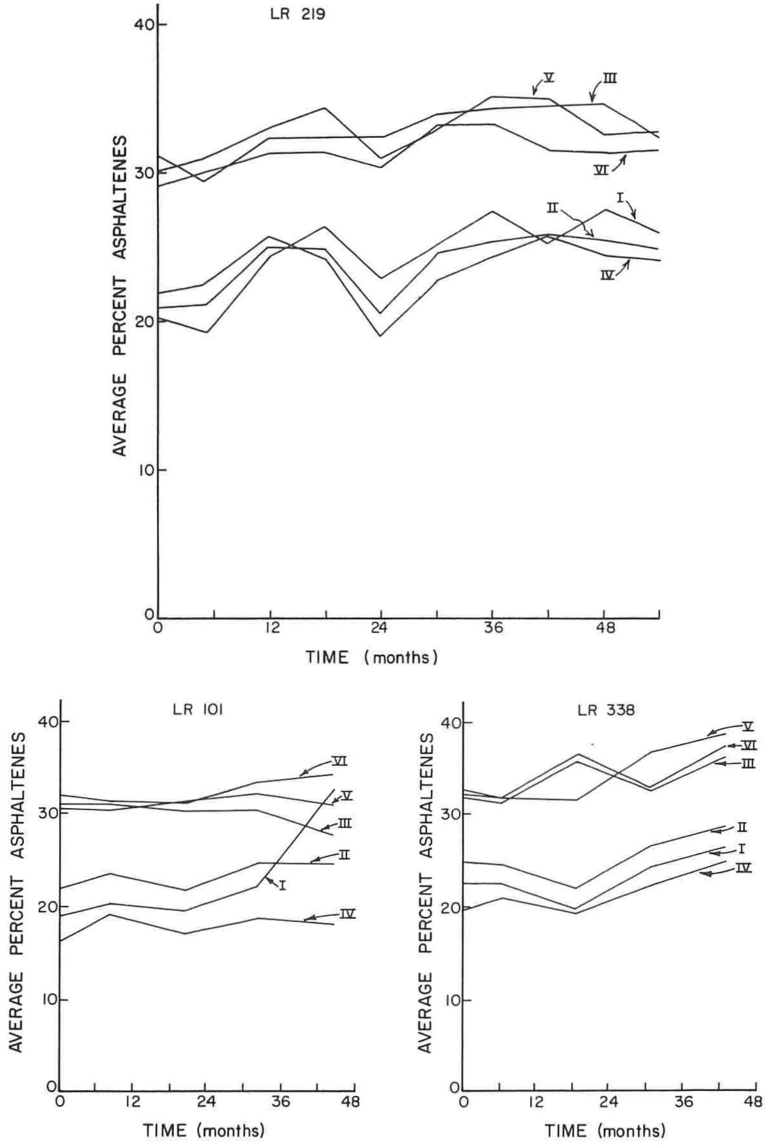


Figure 8. Average percentage of asphaltenes versus time by route.

Specific Gravities, Densities, and Air Voids

It has been suggested earlier in this report that air voids are one of the factors, if not the greatest factor, affecting the rate of hardening of an asphalt pavement. The influence of this variable appears to be so pronounced that it completely overshadows the performance of asphalt type and just about everything else.

Correlating asphalt cement performance with air voids is a very difficult task because of air void variability in an asphalt pavement. The following types of air void variability have been recognized in this research:

1. The inherent variability from point to point in a pavement due to varying degrees of aggregate interlock and asphalt content;

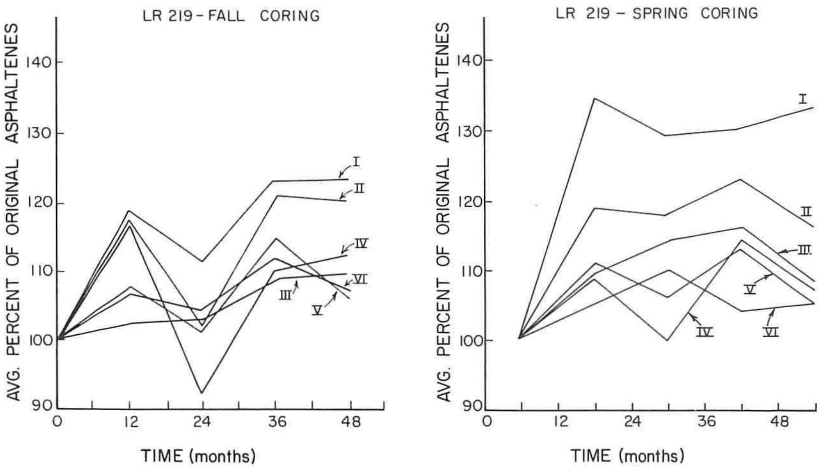


Figure 9. Average percentage of original asphaltenes versus time for LR 219 by coring time.

2. The gently sloping air void trends in the longitudinal direction of the pavement due to variability in gradation, asphalt content, mixing temperature, compaction temperature, and thickness of lift during the construction day;
3. The steeply sloped air void variability across the transverse direction of the pavement due to the decreasing lateral support of the mixture from the center of the traffic lane to its edges during compaction;
4. The air void variability among asphalt cement types on any one pavement due to differences in asphalt cement viscosity during compaction;
5. The air void variability among pavements due to gradation, aggregate type, and differences in degree of hardening in the pug mill;
6. The decrease in air voids with time due to traffic, particularly in the wheel or load zone of a pavement, and the variability in decreases in air voids among asphalt pavements due to differing traffic densities and the degree of initial compaction among pavements.

Figure 10 shows the changes in air voids with time for each asphalt on each pavement. As before, if any durability comparison is to be made between asphalt cement type and air voids, the air void values that must be used are those values that are obtained at the same sampling times each year.

Data given in Table 4 relate percentage of retained penetration and percentage of air voids. Because a comparison among pavements is as desired as a comparison within pavements, the results from the spring samplings must be used. Percentage of retained penetration is based on the first core sample for each pavement. The numbers given in Table 4 were obtained in the following manner (12): By considering only one test pavement and one sampling at a time, the asphalt that showed the highest percentage of retained penetration value was rated 1, the asphalt that showed the second highest percentage of retained penetration value was rated 2, and so on. The asphalt sample that had the lowest percentage of air voids was rated 1, the asphalt sample that had the second lowest percentage of air void value was rated 2,and so on. A tie between the air void and penetration columns means that the relative performance of that asphalt type compared to other asphalts used on the same pavement can be explained completely by the relative value of percentage of air voids for that sample. It should be mentioned that when the air void values among the asphalt mixtures are nearly equal, the asphalt cement type has a greater influence on the durability comparison. The number of ties and a number of instances where the ratings are very close support the strong influence of air voids on pavement durability.

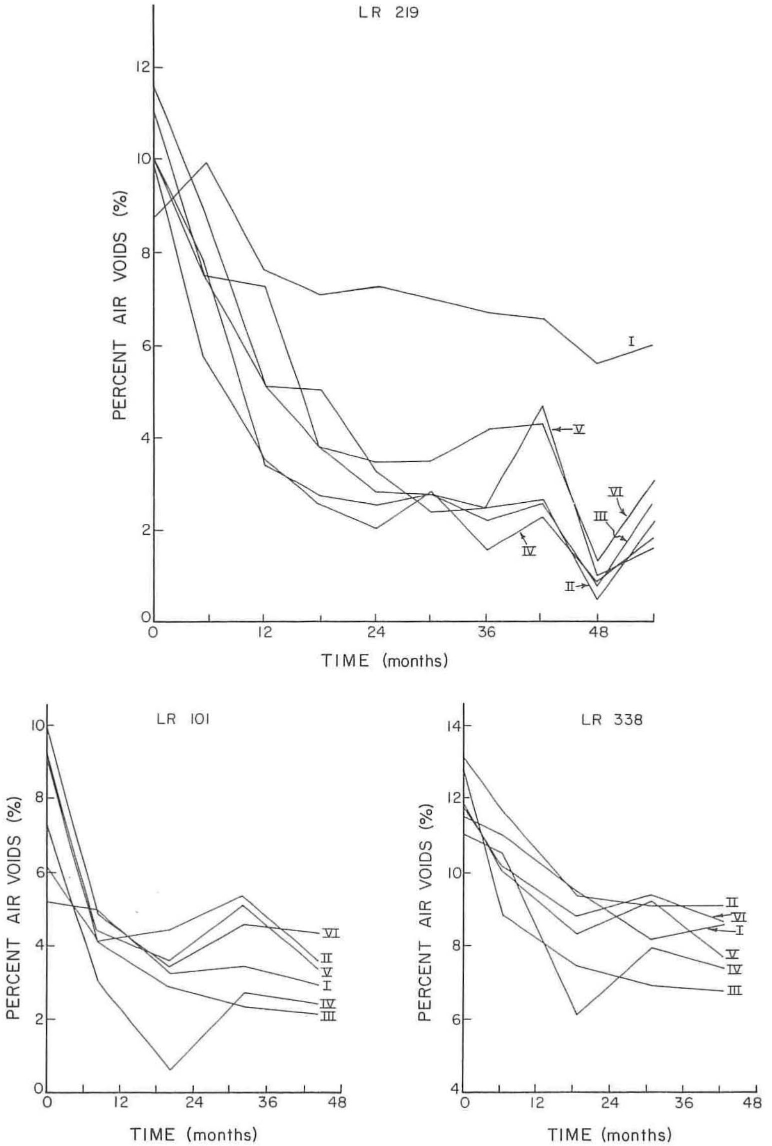


Figure 10. Percentage of air voids versus time by route.

TABLE 4

ASPHALT RATING SYSTEM

Asphalt	LR 219 42 Mo.	LR 219 54 Mo.	LR 101 44 Mo.	LR 338 43 Mo.	LR 219 42 Mo.	LR 219 54 Mo.	LR 101 44 Mo.	LR 338 43 Mo.
	Retained Penetration (percent)				Air Voids (percent)			
I	6	6	3	5	6	6	3	4
II	1	4	4	6	3	3	5	6
III	3	2	2	3	2	4	1	1
IV	2	1	1	2	1	2	2	2
V	5	3	5	4	5	1	4	3
VI	4	5	6	1	4	5	6	5
	Original Viscosity (percent)				Air Void-Time Curve Area			
I	6	6	4	4	6	6	3	5
II	2	4	2	6	3	3	6	6
III	3	5	3	1	2	2	2	1
IV	4	2	1	3	1	1	1	2
V	5	3	5	5	5	4	4	3
VI	1	1	6	2	4	5	5	4

The same analysis was performed by using percentage of original viscosity. The results are closely similar as would be expected because of the correlation that exists between penetration and viscosity (7).

In an attempt to consider the rate of decrease of air voids in a pavement, a slightly different approach can be used. The magnitude of the percentage of air void value is certainly important to the durability of an asphalt pavement, but probably the length of time that it remains at that value is just as important. In other words, will a pavement that remains at a constant level of, say, 4 percent air voids show a greater amount of hardening in some selected period of time than a pavement that had an initial void content of 9 percent air voids and was compacted to a level of 2 percent air voids? There can be no argument that a high initial void content is most detrimental to an asphalt pavement. Most asphalt hardening will occur in the first few years after construction. This hardening also tends to affect the rate of decrease of air voids due to traffic. Figure 11 shows the method employed to compensate for the rate of decrease in air voids with time in an asphalt pavement. Accumulative areas under the air void-time curve are computed for each point in time that a comparison is to be made (12).

Air void-time analysis was performed in a manner similar to that used for the other properties given in Table 4. The asphalt sections on each pavement with the lowest cumulative air void-time areas were rated 1 and so on. Approximately the same degree of success is achieved by this method of analysis as was achieved by simply using percentage of air void values. It would seem that this method of analysis is more logical than the preceding one.

One additional point must be mentioned. The asphalt sections with the lower air void values were constructed with the asphalts of lower initial absolute viscosities. This would mean that more desirable air void values could be achieved during construction of an asphalt pavement by simply using lower viscosity asphalts for identical construction operations used for higher viscosity asphalts. This conclusion has also been drawn by McLeod (14) who presented the advantages of well-designed mixes containing low-viscosity asphalt cements. A close examination of Table 4 indicates that asphalt IV seems superior. Asphalt IV is a 90 to 100 penetration, 900 ± 200 poise viscosity, and a low asphaltene content material.

The decrease of percentage of air voids with time in the wheel or load zone of a pavement by traffic has further implications. Several photographs included in previous reports (12) showed that this compaction of the pavement has completely altered the drainage of water from the pavement to the shoulder. On practically every one of the asphalt pavements being investigated in this study, depressions exist in the wheel zone to the extent that water uses them as drainage ditches. One of the solutions to this problem is to construct asphalt pavements at lower percentage of air voids. Not only pavement safety but also pavement longevity will be increased.

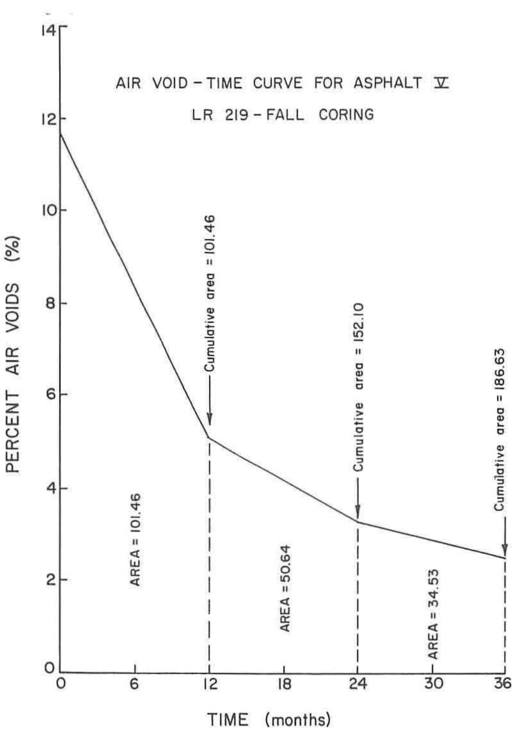


Figure 11. Air void versus time for asphalt V on LR 219, fall coring.

FIELD OBSERVATIONS

During the spring and fall coring operations, a visual inspection was made on each of the 3 pavements. The most important observation made was that

differences in performance among pavements are more noticeable than differences in performance among the different asphalts on the same pavement. Some texture and color differences among asphalts on the same pavement are observable.

The LR 219 pavement, after 54 months of service, continues to show some transverse cracking in all the asphalt sections. The road surface is good, with the asphalt I section being the roughest. It should be recalled that asphalt I has the highest percentage of air voids of all the sections and is hardening at a greater rate than the other sections. Severe edge-cracking as a result of poor shoulders and narrow traffic lanes has been shown photographically in another report (12).

The LR 101 pavement, after 44 months of service, shows some transverse cracking, some longitudinal cracking, and a high aggregate loss in some sections. The poorest conditions appear to exist on the section constructed with asphalt I. This pavement is located in the northern portion of Pennsylvania in an area where there is a high water table. With freezing temperatures, it is most probable that this pavement has been subjected to differential movement. This could be an explanation for the surface cracks that have developed.

The LR 338 pavement, after 43 months of service, continues to exhibit transverse reflection cracking and centerline cracking in all asphalt sections.

SUMMARY

It is still comparatively early to evaluate the quality and aging characteristics of the asphalts used in these experimental pavements. However, a very basic rating system indicates that asphalt IV (90 to 100 penetration and 900 ± 200 poise viscosity) is as good as or better than any of the other asphalts. This statement will be validated if the test projects are studied until final deterioration occurs or until portions of the pavements are reclaimed, reconstituted, or resurfaced.

From the data presented, the following conclusions can be made:

1. In general, all the asphalts are hardening with time based on physical test data and percentage of asphaltenes.
2. The time of year when a pavement is sampled is a factor influencing test results among test pavements and within test pavements. All test pavements should be sampled at the same time each year on an annual basis.
3. The major contribution to asphalt hardening appears to occur in the warmer months of the year. An additional 5 to 6 months of pavement life may be realized if the pavement is built in the fall rather than in the spring. This would allow some pavement compaction to occur prior to the time the agents of asphalt hardening become active.
4. The concept of percentage of retained penetration and percentage of original viscosity used in analyzing data may be a better indicator of the relative merits of the 6 test asphalts.
5. The air void volume of an asphalt pavement is a major factor influencing pavement durability and the safety of those using the pavement. Development of a rating system based on air void changes and asphalt property changes with time shows promise in evaluating the 6 text asphalts.

REFERENCES

1. Sisko, A. W., and Brunstrum, L. C. Relation of Asphalt Rheological Properties to Pavement Durability. NCHRP Rept. 67, 1969, 45 pp.
2. Brown, A. B., Sparks, J. W., and Larson, D. Rate of Change of Softening Point, Penetration, and Ductility of Asphalt in Bituminous Pavement. Proc. AAPT, Vol. 26, 1957, pp. 66-81.
3. Hveem, F. N., Zube, E., and Skog, J. Progress Report on the Zaca-Wigmore Asphalt Test Project. ASTM, STP 277, Sept. 1960, pp. 3-45.
4. Kenis, W. J., Sr. Progress Report on Changes in Asphaltic Concrete in Service. HRB Bull. 333, 1962, pp. 39-65.

5. Gotolski, W. H., Ciesielski, S. K., and Heagy, L. N. Progress Report on Changing Asphalt Properties of In-Service Pavements in Pennsylvania. Proc. AAPT, Vol. 33, 1964, pp. 285-319.
6. Gotolski, W. H., Ciesielski, S. K., Smith, R. W., and Kofalt, J. A. Study of Physical Factors Affecting the Durability of Asphaltic Pavements. Highway Research Record 231, 1968, pp. 1-23.
7. Gotolski, W. H., Ciesielski, S. K., Smith, R. W., and Kofalt, J. A. A Study of Physical Factors Affecting the Durability of Asphaltic Pavements. Pennsylvania State Univ., Research Rept. IR-8, Sept. 1967, 199 pp.
8. Rostler, F. S., and White, R. M. Influence of Chemical Composition of Asphalts on Performance, Particularly Durability. ASTM, STP 277, 1960, pp. 64-88.
9. Rostler, F. S., and White, R. M. Composition and Changes in Composition of Highway Asphalts, 85-100 Penetration Grade. Proc. AAPT, Vol. 31, Jan. 1962, p. 35.
10. White, R. M., Mitten, W. R., and Skog, J. B. Fractional Components of Asphalts—Compatibility and Interchangeability of Fractions Produced From Different Asphalts. Paper presented at AAPT Annual Meeting, Kansas City, Missouri, Feb. 1970.
11. Gotolski, W. H., Lucas, J. M., Ciesielski, S. K., and Kofalt, J. A. Chemical Analysis Test—Procedure, Precision and Results. Pennsylvania State Univ., Interim Rept. 3, July 1965.
12. Gotolski, W. H., Smith, R. W., and Roberts, J. M. A Study of Physical Factors Affecting the Durability of Asphaltic Pavements. Pennsylvania State Univ., Research Rept. IR-9, Sept. 1968, 147 pp.
13. Gotolski, W. H., Smith, R. W., and Roberts, J. M. A Study of Physical Factors Affecting the Durability of Asphaltic Pavements. Pennsylvania State Univ., Research Rept. IR-10, Sept. 1969, 107 pp.
14. McLeod, N. W. Influence of Viscosity of Asphalt Cements on Compaction of Paving Mixtures in the Field. Highway Research Record 158, 1967, pp. 76-115.

GENERAL DISCUSSION OF VISCOSITY GRADING OF ASPHALTS

R. J. Davis, Koppers Company, Inc., Verona, Pennsylvania

•ABOUT 10 years ago a program was launched to determine the consistency of asphaltic materials in fundamental units. I am a strong supporter of this program. Part of this program was a search for new, simpler methods for determining the viscosity of asphalts. I also heartily support this effort. Somewhere along the way, the program seems to have become bogged down insofar as asphalt cements are concerned, because no simple, precise method for determining viscosity of asphalt cements at lower temperatures has been widely accepted.

This problem appears to me to be largely due to the sensitivity of consistency measurements of many asphalt cements at lower temperatures to even moderate changes in shear rate. The penetration method that has been used most widely in the past to measure asphalt cement consistencies at lower temperatures usually shears the asphalt sample at higher shear rates than most of the newer viscosity methods. This leads to differences that are supposed to show that the penetration method is inferior. It appears obvious to me that; no matter what method of test is used, different consistency values will be obtained at different shear rates at the lower temperatures where most asphalt cements are shear susceptible.

The efficacy of the penetration method is not of prime importance. The important matter is the determination and control of those rheological properties of the asphalt cement that have an important effect on the finished pavement. I think these important properties are the viscosity of the binder at the mixing temperature, at the compaction temperature, at the highest temperature that the pavement reaches in service, and at the lowest temperature that the pavement reaches in service. These 4 rheological properties can be divided into those that we can control and those that we cannot. We have little control over the highest and lowest temperatures that the pavement will reach. We can control the temperature of mixing and compacting the pavement and, through this control, the viscosity of the binder during these operations. Because we cannot control the highest and lowest temperatures in the pavement, it is an important function of the specifications to control the rheological properties of the binder at these temperatures.

I think that viscosity at 140 F as determined by ASTM Method D 2171-66 is satisfactory for the control of viscosity at the highest temperature. I do not think that we have a satisfactory method of controlling the viscosity of the binder at the lowest temperature in the pavement. The proposal for controlling the viscosity at low temperatures through the combination of viscosity controls at 275 and 140 F plus a minimum penetration causes me some concern especially when I realize that many people want to eliminate the penetration requirement. The precision of the viscosity methods at 275 and 140 F are not as good as we would like but they are certainly usable.

The real precision problem is apparent when we try to use viscosity specifications at 140 and 275 F to control the low temperature properties of the binder. The imprecision of the viscosity methods at 140 and 275 F is greatly increased by using them in combination, and this imprecision is multiplied by extrapolating the result down to the lowest temperature in the pavement. This is the great disadvantage of this type of specification.

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I do not think that anyone would have suggested controlling the low temperature properties in this manner if a reasonable test method for determining these low temperature properties directly had been available. It appears to me that we must again make an effort to develop a test method capable of measuring the low temperature properties of the binder. I do not think that the penetration test is satisfactory for this purpose even though it may be used as an interim method while a better method is being developed. The required method should be capable of measuring the properties in fundamental units of the binder at the lowest temperatures expected in the roadway and at stresses and strains similar to those encountered in the pavement.

The type of specification for the rheological properties of asphalts that I envision is one that would set viscosity limits at 140 F or some other high temperature and then set a maximum low temperature at which the binder must perform satisfactorily in a pavement based on the new test method results. There would be no specification requirements for the viscosity over 140 F, but the supplier might be required to give the temperatures at which the binder reached certain viscosities for mixing and compaction.

H. J. FROMM AND W. A. PHANG, Closure—We do not have much to add in the way of comments to this discussion. Our position has already been stated in our paper. We believe a minimum viscosity specification is necessary at 275 F in order to control the viscosity of the mix at road construction temperatures. A maximum viscosity specification at low temperatures (around the freezing point) would also be of great use in ensuring good low-temperature performance from pavements in the colder regions of our countries. Concerning the temperature, however, at which the asphalts are graded, we believe 140 F is too close to the temperature region in which the waxes are melting (or solidifying) to be safely used as a temperature for control purposes. It is quite possible that an asphalt cement could be obtained where its waxes were melting in this temperature region and then the test results would not be reproducible. We believe some other temperature should be selected. Because a great deal of experience has been obtained over the years with asphalts graded at 77 F, we see little reason to change from this temperature. We urge that every effort be made to develop a test method by which viscosities may be easily and reproducibly determined at 77 F.

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